

Article

Generative Learning and Student Motivation in Middle-School Science: Evidence from a Quasi-Experimental Study

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Abstract

The present study examined whether seventh-grade female students in Oman who were taught through the generative learning model showed higher posttest science achievement and motivation to learn science than students who received regular instruction. The study used a pretest-posttest quasi-experimental design with non-equivalent groups. There were 56 student participants, with 28 in the experimental group and 28 in the control group. The experimental group was taught using a teacher's guide organized around the stages of the generative learning model, whereas the control group received regular instruction for the same Grade 7 science unit. Student outcomes were assessed using an academic achievement test covering knowledge, application, and reasoning, and a motivation toward learning science scale. Pretest evidence indicated baseline equivalence between the two groups on achievement, Wilks' Lambda = 0.939, $F(3, 52) = 1.13$, $p = 0.346$, and motivation, Wilks' Lambda = 0.943, $F(6, 49) = 0.489$, $p = 0.807$. Posttest comparisons showed higher achievement and motivation scores for the experimental group under the conditions of the study. The findings provide preliminary context-specific evidence that generative learning may be associated with stronger cognitive and motivational outcomes in middle-school science, although the intact-class design warrants cautious interpretation.

Keywords: generative learning; science achievement; motivation to learn science; science learning; middle school students

1. Background

Contemporary perspectives on learning increasingly view students as active meaning makers rather than passive recipients of information, encouraging greater attention to instructional approaches that engage learners in constructing knowledge, connecting new information to prior experience, and participating actively in the learning process (García, 2011). Constructivist theory provides a useful foundation for this perspective, conceptualizing learning as an active process in which learners interpret and reorganize experience through existing knowledge structures, while teachers facilitate rather than simply transmit information (Baviskar et al., 2009; Harjali, 2019).

From a constructivist perspective, motivation is not merely an accompanying outcome of effective instruction; rather, it is one of the central conditions through which learning is initiated, sustained, and deepened. Students with stronger motivation are generally more likely to persist in challenging tasks, invest effort, regulate their engagement, and pursue achievement-oriented goals (Al-Hinai et al., 2026; Al-Muqbali et al., 2026). Ultimately,



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these processes are closely associated with improved academic performance and a greater willingness to overcome difficulties in learning contexts (Al-Huwaidi, 2005; Çetin-Dindar, 2016; Ciarrochi et al., 2001; Santrock, 2003). Academic achievement is therefore examined here as one of the primary outcomes through which the effects of motivation become observable. To the extent that learning environments foster student motivation, they may also strengthen the cognitive and self-regulatory processes that support successful academic performance over time (Abu Ahmead, 2022; Al-Jahriya, 2010).

A growing body of research in Oman and other contexts has highlighted the importance of motivation in shaping academic achievement and has drawn attention to instructional models that move beyond transmission-oriented teaching. Among these, the generative learning model is particularly relevant because it assumes that meaningful learning occurs when students actively generate relationships between prior knowledge and new ideas, rather than simply receive information passively from the teacher (Appiah-Twumasi, 2019; Buchner, 2022; Fiorella & Mayer, 2016; Ormrod, 2011; Pang, 2019; Xie et al., 2019). In this sense, the model is potentially important not only as a pedagogical strategy but also as a motivational one: the cognitive activities it emphasizes—recalling prior knowledge, organizing ideas, generating explanations, and reflecting on understanding—may help support students' engagement and motivation to learn.

The generative learning model is grounded in the assumption that deeper learning depends on learner-driven construction of meaning (Fiorella & Mayer, 2016; Maknun, 2015; Ulusoy & Onen, 2014). Generative learning occurs through a set of interrelated processes that may also help explain variation in students' motivation to learn (Anderman, 2010; Çetin-Dindar, 2016). One such process is the activation of prior knowledge and experience, through which learners retrieve relevant ideas, connect content to familiar situations, and confront misconceptions through discussion and questioning (Al-Maliki & Mutawa, 2020; Fiorella & Mayer, 2016; Ormrod, 2011). A second process involves motivational activation, as students are encouraged to investigate phenomena, explore ideas, and develop confidence in their capacity to understand challenging concepts (Anderman, 2010; Appiah-Twumasi, 2019; Abulibdeh et al., 2016). A third process is attentional engagement, in which students' focus is directed toward meaningful scientific questions and explanatory tasks, thereby sustaining their involvement in learning activities (Çetin-Dindar, 2016). A fourth process, generation itself, lies at the center of the model, because students are required to produce meaning through interpretation, explanation, and collaborative knowledge construction (Basaffar, 2017; Fiorella & Mayer, 2016; Yuliani et al., 2021). Finally, the model incorporates metacognitive activity by prompting learners to monitor, question, and reflect on their own understanding, thereby increasing the likelihood that knowledge will be transferred and used flexibly in new situations (Fiorella & Mayer, 2016).

Viewed together, these processes suggest that the value of the generative learning model may lie in its ability to align cognitive engagement with motivational engagement (Anderman, 2010; Çetin-Dindar, 2016; Fiorella & Mayer, 2016). When students are encouraged to activate prior knowledge, connect new information to what they already know, generate explanations, and reflect on their understanding, they are not only processing content more deeply but also participating in forms of learning that may strengthen persistence, confidence, and active involvement (Appiah-Twumasi, 2019; Abulibdeh et al., 2016; Ormrod, 2011). This is particularly relevant in science education, where conceptual understanding often depends on sustained attention, explanation of phenomena, and the integration of abstract ideas with prior experience (Al-Huwaidi, 2005; Maknun, 2015; Ulusoy & Onen, 2014).

The same processes have also been described in the generative learning literature through four closely connected elements: recall, integration, organization, and elaboration

(Al-Zubaidi, 2019; Kamil, 2022). Recall corresponds to the activation of prior knowledge from long-term memory. Integration refers to linking new information with prior understanding to form more coherent meaning. Organization involves structuring ideas in meaningful and connected ways, and elaboration extends understanding by generating additional interpretations, relations, and explanations. Framed in this way, these elements map directly onto the processes described above and reinforce the view that learning in the generative model is not the accumulation of isolated facts, but an active constructive process in which learners transform information into personally meaningful knowledge.

Recent international studies have supported the use of this model. For example, studies examining generative learning in physics and biology education have reported improvements in conceptual mastery, achievement, and motivational engagement when learners are required to generate explanations, organize ideas, and connect new information with prior knowledge (Dewi et al., 2020; Onanuga et al., 2020; Yuliani et al., 2021). Similarly, Buchner (2022) showed that generative learning strategies can be integrated with technology-enhanced learning environments without diminishing students' attitudes toward learning, which supports the continued relevance of generative learning for contemporary science classrooms.

In classroom practice, the model is typically implemented through a sequence of instructional stages, including a preparatory stage that activates prior experience, a focus stage that often uses small-group interaction, a challenge stage in which existing ideas are questioned and revised, an application stage that extends learning to practical contexts, and an evaluation stage that assesses the effectiveness of these learning experiences (Al-Maliki & Mutawa, 2020). Rather than functioning merely as procedural steps, these stages can be understood as organizing the kinds of learner activity central to generative learning. Specifically, they prompt students to activate prior knowledge, engage in discussion, revise initial ideas, generate explanations, apply concepts in new contexts, and reflect on their understanding. Framing the stages in this manner better highlights how the model supports the cognitive engagement and motivated participation associated with meaningful learning. Empirical studies in science education have reported positive effects of the generative learning model across a range of outcomes. Prior work has shown that this model can improve scientific concepts, critical thinking, reflective thinking, engagement, creativity, and mastery of physical concepts when compared with more conventional approaches (Dewi et al., 2020; Maknun, 2015; Yuliani et al., 2021). Although these findings support the instructional promise of the model, they also point to a broader theoretical issue: the extent to which learning gains may be explained by the model's capacity to activate cognitive generation, sustain attention, and strengthen students' motivation to engage with science learning tasks.

Within the Omani school context, the need for approaches such as this is particularly important. Science education in Oman has increasingly emphasized active participation, conceptual understanding, and student engagement; however, classroom practice is still shaped by curriculum coverage requirements, time-limited units, and assessment expectations that may encourage more teacher-directed forms of instruction. Existing Omani and regional studies have drawn attention to students' motivation toward science and to the value of constructivist approaches, but direct evidence on the use of the generative learning model in Omani middle-school science remains limited (Ambusaidi & Al-Hosani, 2018; Abulibdeh et al., 2016). This contextual gap makes it necessary to examine whether the model can operate effectively within the realities of Omani public-school classrooms and whether it can support both cognitive and motivational outcomes at the same time.

Thus, the significance of studying the generative learning model lies in these dual outcomes, that is, not only in determining whether it improves achievement, but also in

understanding how its underlying processes may foster motivated learning. Framing the model in this way makes it possible to examine it as more than a classroom technique. It becomes a theoretically relevant context for investigating how these generative cognitive processes may work together with motivational engagement in academic learning.

2. The Present Study

Building on this rationale, the problem addressed in this study is that, despite continuing concern about science achievement and students' motivation to learn science in Oman, there is still limited empirical evidence on whether instructional models that require students to actively generate meaning can improve both outcomes simultaneously in middle-school science. Much of the available work has examined achievement, motivation, or related constructivist practices separately, leaving an important gap in understanding how the generative learning model may support the cognitive and motivational dimensions of science learning together (Appiah-Twumasi, 2019; Abulibdeh et al., 2016; Kamil, 2022). This gap is both empirical and practical: empirically, there is a need for quasi-experimental evidence situated in the Omani context; practically, teachers need models that can be implemented within regular curriculum units while still promoting active knowledge construction and sustained motivation.

The need for this study is also justified by local classroom concerns. Prior work in the Omani context has highlighted persistent challenges in science learning and the need to diversify teaching methods beyond traditional instruction (Ambusaidi & Al-Hosani, 2018; Abulibdeh et al., 2016). In addition, a preliminary exploratory inquiry conducted with 21 Grade 7 science teachers across several Omani governorates suggested that low academic achievement may be accompanied by weak motivation to learn science. Teachers attributed these difficulties to reduced motivation, curriculum demands, assignment load, ineffective study habits, social media distraction, limited instructional time, and developmental factors. Most respondents also indicated that the generative learning model may be useful because it encourages the activation of prior knowledge, the construction of new understanding, and students' confidence in their own learning.

Against this background of classroom issues, and in response to the identified empirical gap, the present study examined whether the generative learning model could improve science achievement and motivation to learn science among seventh-grade female students in the Sultanate of Oman. The study therefore responds to a clear gap in local evidence by testing a structured, theory-informed instructional model in an authentic middle-school science context.

Given that the study was implemented in authentic school settings with intact classes, the research questions were addressed with attention to the constraints of quasi-experimental classroom research. The findings are therefore interpreted as evidence of group differences associated with the instructional intervention under the specific parameters of this study, rather than as evidence that fully rules out teacher, classroom, or school effects.

The study addressed the following research questions (RQs) and hypotheses (H):

RQ1: What posttest differences in science achievement are observed between seventh-grade female students taught through the generative learning model and those taught through regular instruction in the Sultanate of Oman?

H1. *There is no statistically significant difference at the $\alpha = 0.05$ level between the mean posttest achievement scores of students in the experimental group and those in the control group.*

RQ2: What posttest differences in motivation to learn science are observed between seventh-grade female students taught through the generative learning model and those taught through regular instruction in the Sultanate of Oman?

H2. *There is no statistically significant difference at the $\alpha = 0.05$ level between the mean posttest motivation scores of students in the experimental group and those in the control group.*

3. Method

3.1. Design and Participants

The study employed a pretest–posttest quasi-experimental design with non-equivalent groups. This design was used because the intervention was implemented in intact school classes, and individual random assignment of students was not feasible within the normal organization of public-school classrooms. Two cooperating public girls' schools were intentionally selected because they met the practical requirements for implementation, including administrative approval, teacher cooperation, and timetable compatibility. One intact Grade 7 class was then assigned to the experimental condition and one intact Grade 7 class to the control condition. Both groups completed the academic achievement test and the motivation toward learning science scale before and after the intervention.

The participants were 56 seventh-grade female students. The experimental group included 28 students and was taught using the generative learning model, whereas the control group included 28 students and received regular instruction without the generative learning model. The focus on female students reflects the organization of schooling in the study context and the administrative access available for conducting the intervention in all-girls schools.

In light of the use of these intact classes, several procedures were used to reduce selection bias and strengthen internal validity. First, both groups were drawn from the same grade level and studied the same science unit during the same school semester. Second, pretest scores on both outcome measures were used to check baseline equivalence before the intervention. Third, the two teachers had the same length of teaching experience (10 years), which helped reduce teacher-related variation between groups. Fourth, the instructional conditions were kept as equivalent as possible in terms of content coverage, instructional time, learning objectives, and assessment procedures. Thus, the principal intended difference between the two groups was the independent variable: the use of the generative learning model in the experimental group and regular instruction in the control group.

Nevertheless, because the two groups were taught by different teachers in different schools, the treatment condition was confounded with school, classroom, and teacher factors. However, no independent lesson-by-lesson observation score or separate instructional-quality questionnaire result was available. For this reason, teacher and school differences are treated as limitations rather than as fully controlled factors. Even so, these procedures cannot fully remove the confounding of treatment condition with school, classroom, and teacher factors. The findings should therefore be interpreted as differences observed between two intact classroom groups under the conditions of this study, rather than as definitive evidence that the intervention alone caused all posttest differences. Consequently, school culture, classroom climate, and teacher enactment may have contributed to the observed posttest differences, even though the same unit, instructional time, and assessment instruments were used across conditions.

3.2. Materials

3.2.1. Academic Achievement Test

An academic achievement test was developed to assess students' learning in the Grade 7 science unit *Living Organisms in Their Environment*. The test was constructed using the Student Learning Assessment Document for Science Subjects for Grades 5–9 issued by the Educational Measurement and Evaluation Centre for the 2022/2023 academic year. A table of specifications was prepared to ensure alignment between the test content and the targeted cognitive levels. The test included three levels: knowledge (40%), application (40%), and reasoning (20%). The knowledge level assessed students' recall and recognition of scientific facts, concepts, and basic information related to the unit content. The application level measured students' ability to use what they had learned in familiar or slightly modified contexts, such as interpreting examples, solving routine problems, and applying concepts to classroom-based situations. The reasoning level focused on higher-order thinking by assessing students' ability to analyze relationships, draw conclusions, explain phenomena, and use evidence-based thinking in responding to science-related tasks. The distribution of items across these three levels was intended to provide a balanced measure of students' mastery of content, their ability to use that content meaningfully, and their capacity for scientific reasoning. The relative weight assigned to each topic was determined according to the number of instructional periods devoted to that topic in the unit (see Table 1).

Table 1. The relative weight of the lessons in the unit (*Living Organisms in Their Environment*).

Topic	Number of Lessons	Knowledge (40%)	Application (40%)	Reasoning (20%)	Total Number of Questions
Adaptation	2	1	1	0	2
Food chains	1	1	0	0	1
Food webs and energy transfer	2	1	0	1	2
Decomposers	3	1	1	1	3
Humans and food chains	2	1	1	0	2
Pollution	3	1	1	1	3
Ozone layer depletion	2	0	1	1	2
Environmental conservation	2	1	1	0	2
Study of a naturalist	1	0	1	0	1
Population count	2	1	1	0	2
Total	20	8	8	4	20

After these validation steps, the final version of the test consisted of 20 objective items distributed across the three cognitive levels and arranged according to the sequence of topics in the unit. An answer key was prepared for scoring, and clear instructions were provided on the first page of the instrument.

To establish content validity, the initial version of the test and its answer key were reviewed by 10 specialists, including curriculum experts, supervisors, senior teachers, and science teachers. Reviewers evaluated the linguistic clarity, grade-level appropriateness, and scientific accuracy of the items. Their comments led to several revisions, including refining the wording of selected items, adjusting some response options, and standardizing item phrasing. After incorporating these revisions, the test was finalized in its 20-item form. These procedures ensured that the assessment was aligned with the Omani Grade 7 science curriculum and appropriate for the linguistic and developmental level of the target students.

The test was piloted with a group of Grade 7 students outside the main study sample to examine its psychometric properties. Test–retest reliability over a two-week interval yielded a Pearson correlation coefficient of 0.83 for the total score. Reliability coefficients

for the subdomains were 0.94 for knowledge, 0.88 for application, and 0.76 for reasoning. Internal consistency was also acceptable, with a Cronbach's alpha of 0.82. Together, these values indicate that the test was sufficiently reliable for use in the study. The final version of the test is provided in Section S1.

Additional item-level analyses further supported the adequacy of the instrument. Item-total correlations were all positive and statistically significant, ranging from 0.377 to 0.878, suggesting satisfactory internal consistency. In addition, item difficulty indices ranged from 0.38 to 0.73, while discrimination indices ranged from 0.20 to 0.65, both of which fall within acceptable ranges for educational assessment purposes (Awda, 2010).

Participants were given 40 min to take the test, based on the average completion time observed during the pilot phase. For scoring, one point was awarded for each correct answer and zero points for each incorrect answer, yielding a maximum possible score of 20.

The same achievement test was administered as both the pretest and the posttest in order to make baseline and post-intervention scores directly comparable. To reduce possible practice effects, the interval between administrations covered the full intervention period, students were not given the answer key, and the posttest was administered after completion of the instructional unit. Nevertheless, the repeated use of the same test is acknowledged as a possible limitation when interpreting gain-related evidence.

3.2.2. Motivation Toward Learning Science Scale

Students' motivation toward learning science was measured using a scale adapted from Ibrahim (2019), which in turn was based on the work of Abulibdeh et al. (2016) and Tuan et al. (2005). The scale was designed to assess the effect of the generative learning model on seventh-grade female students' motivation toward learning science. It consists of 35 items rated on a five-point Likert scale ranging from strongly agree to strongly disagree. The items are distributed across six dimensions: self-efficacy, active learning strategies, value of learning science, performance goals, science achievement goals, and stimulating learning environment.

The self-efficacy dimension includes seven items that assess students' confidence in themselves, their perceived ability to solve problems, and their ability to generate ideas related to scientific concepts. The active learning strategies dimension consists of eight items focusing on learning strategies that help students acquire new scientific concepts and connect them with prior knowledge. The value of learning science dimension includes five items that address the perceived importance of science learning and its contribution to problem solving and inquiry-based activity. The performance goals dimension consists of four items reflecting students' desire to participate in science learning, obtain high grades, and distinguish themselves from peers. The science achievement goals dimension includes five items related to students' satisfaction with their success in science and their sense of acceptance when presenting ideas in the classroom. Finally, the stimulating learning environment dimension consists of six items assessing students' enthusiasm for science learning in relation to the diversity of content, variation in teaching methods, and reduced classroom pressure (Ibrahim, 2019; Tuan et al., 2005).

In Ibrahim's (2019) study, the scale demonstrated acceptable psychometric properties. Face validity was established, and reliability was supported through both test-retest reliability, which yielded a coefficient of 0.94, and internal consistency reliability, with a Cronbach's alpha of 0.79. In the current study, the scale was reviewed by six judges to assess its appropriateness for seventh-grade female students and its suitability for the Omani context. Based on their feedback, minor revisions were made, including shortening and rephrasing the introductory instructions, replacing the term science subject with science course, and adjusting the wording of some items to improve clarity for students. This

review helped ensure that the adapted version measured motivation toward learning science in a manner suitable for the Omani Grade 7 context.

To establish reliability in the current study, the scale was administered to a pilot sample of 31 seventh-grade students drawn from outside the main study sample. Internal consistency was then calculated using Cronbach's alpha, which yielded a coefficient of 0.87, indicating acceptable reliability for the purposes of the study. The final version of the scale is provided in Section S2.

Because Arabic was the language of instruction in the participating schools, the scale was administered in Arabic. Responses to positively worded items were scored from 1 (strongly disagree) to 5 (strongly agree). Items 2, 4, 5, 6, and 7 in the self-efficacy dimension were negatively worded and were reverse-scored before calculating item-dimension correlations, reliability coefficients, self-efficacy scores, total motivation scores, and inferential statistics (1 to 5, 2 to 4, 3 unchanged, 4 to 2, and 5 to 1). Thus, higher scores consistently indicated stronger motivation toward learning science. Section S2 provides a complete English translation of the Arabic scale administered to participants; the (R) labels are included only to make the scoring transparent and were not shown to participants. The six-dimensional structure was retained from the source scale and was further supported by the pattern of item-dimension correlations reported in Table 2; however, because confirmatory factor analysis was not conducted with the relatively small pilot sample, construct validity is interpreted cautiously.

Table 2. Item–dimension correlation coefficients for the motivation toward learning science scale.

Dimension	Item No.	Item–Dimension Correlation
Self-efficacy	1	0.373 **
	2	0.509 **
	3	0.463 **
	4	0.668 **
	5	0.751 **
	6	0.599 **
	7	0.656 **
Self-efficacy total		0.704 **
Active learning strategies	8	0.495 **
	9	0.576 **
	10	0.630 **
	11	0.503 **
	12	0.428 **
	13	0.406 **
	14	0.511 **
	15	0.603 **
Active learning strategies total		0.645 **
Value of learning	16	0.613 **
	17	0.762 **
	18	0.773 **
	19	0.606 **
	20	0.460 **
Value of learning total		0.672 **
Performance goals	21	0.501 **
	22	0.629 **
	23	0.813 **
	24	0.804 **
Performance goals total		0.549 **

Table 2. *Cont.*

Dimension	Item No.	Item–Dimension Correlation
Science achievement goals	25	0.555 **
	26	0.683 **
	27	0.682 **
	28	0.712 **
	29	0.880 **
Science achievement goals total		0.643 **
Stimulating learning environment	30	0.651 **
	31	0.730 **
	32	0.719 **
	33	0.635 **
	34	0.628 **
	35	0.740 **
Stimulating learning environment total		0.800 **

Note. ** $p < 0.01$.

To further examine internal consistency, item–dimension correlations were also examined. As shown in Table 2, all correlation coefficients were positive and statistically significant at the 0.01 level, indicating adequate internal consistency between each item and its corresponding dimension, and supporting the suitability of the scale for use in the study.

3.3. Procedure and Data Analysis

3.3.1. Procedure

The first step of the procedure was a review of relevant Arabic and international literature to establish the conceptual and empirical background for the investigation. This was followed by an exploratory preliminary inquiry with Grade 7 science teachers to refine the local rationale for the study and to identify classroom concerns related to achievement and motivation in science. Based on the goals of the study, Unit Seven, Living Organisms in Their Environment, from the Grade 7 science curriculum was selected as the instructional unit for implementation.

To ensure that the intervention was implemented systematically, a teacher’s guide based on the generative learning model was developed for the selected unit. The guide included lesson plans, classroom activities, worksheets, and supporting electronic resources organized around the stages of the model: preparation, focus, challenge, application, and evaluation. The guide was reviewed by specialists, and necessary revisions were made before implementation. The academic achievement test and the motivation toward learning science scale were also reviewed, piloted, and checked for validity and reliability before the main study.

Following official approval from the Ministry of Education, the two groups completed the academic achievement test and the motivation toward learning science scale as pretests. Baseline equivalence for achievement and motivation was examined before the intervention. The cooperating teacher in the experimental group was trained to implement the instructional procedures outlined in the teacher’s guide, including how to activate students’ prior knowledge, organize group discussion, guide students through challenge and application tasks, and conclude each lesson with evaluation and reflection.

The intervention was then implemented from 26 February 2023 to 23 March 2023 during the regular school timetable. The target unit included 20 instructional periods distributed across the topics shown in Table 1. During this period, the experimental group was taught using the generative learning model, whereas the control group received

regular instruction for the same unit, over the same instructional period, and with the same learning objectives and assessment instruments. At the end of the intervention, both the academic achievement test and the motivation scale were re-administered to the two groups as posttests.

3.3.2. Classroom Implementation of the Intervention and Control Condition

In the experimental group, each lesson followed the five stages of the generative learning model: preparation, focus, challenge, application, and evaluation. In the preparation stage, the teacher activated students' prior knowledge through short questions, familiar examples, and discussion of students' initial ideas. In the focus stage, students worked individually or in small groups to organize relevant information from the lesson and connect it to prior knowledge. In the challenge stage, students compared explanations, discussed conflicting ideas, and revised incomplete or inaccurate understandings. In the application stage, students used the new concepts to interpret examples from the unit, such as food chains, pollution, environmental conservation, and population count. In the evaluation stage, students completed short questions, worksheets, oral explanations, or reflection tasks to check understanding and consolidate learning.

In this sequence, the teacher's guide served as the main implementation tool. It specified lesson objectives, expected teacher prompts, student tasks, worksheet activities, electronic resources, approximate time allocations, and the role of students in discussion, explanation, and reflection. Examples of generative activities included asking students to explain relationships among organisms, construct or complete food-chain and food-web examples, justify causes and effects of pollution, compare environmental solutions, and apply ecological concepts to familiar Omani contexts.

Across the 20 instructional periods, the sequence of student tasks included individual recall questions, small-group discussion, food-chain and food-web construction, explanation of pollution-related problems, interpretation of environmental examples, and completion of worksheets that required students to generate, revise, and apply scientific explanations.

In contrast, the control group received regular instruction for the same unit. Regular instruction included teacher explanation, textbook-based discussion, question-and-answer exchanges, completion of textbook or workbook activities, and teacher-led correction of students' responses. Students in the control group participated in classroom tasks, but the lessons were not organized explicitly around the five stages of the generative learning model and did not systematically require students to generate, challenge, revise, and apply explanations through the structured sequence used in the experimental group.

3.3.3. Implementation Fidelity and Control of Confounding Variables

To support implementation fidelity, the study relied on standardization of the instructional materials and procedures. The teacher's guide specified the lesson objectives, learning activities, worksheets, electronic resources, time allocations, teacher prompts, and expected teacher and student roles for each lesson. Before implementation, the cooperating teacher in the experimental group received orientation on the stages of the generative learning model and on the use of the guide. During the intervention, the research team followed up on the implementation schedule, reviewed the use of lesson activities and worksheets, and checked that the stages of preparation, focus, challenge, application, and evaluation were represented across lessons.

In parallel, potential confounding variables were addressed procedurally. Both groups studied the same curriculum unit, completed the same number of instructional periods, worked toward the same learning objectives, and completed the same assessment instru-

ments. The two teachers also had the same length of teaching experience (10 years), and both outcome measures were administered before the intervention to examine baseline comparability. These procedures were intended to reduce differences in prior knowledge, instructional time, content coverage, teacher experience, and assessment conditions.

Instructional quality was not independently quantified through lesson-by-lesson observation or a separate questionnaire score. Accordingly, instructional equivalence was not treated as an empirically measured equivalence variable. Group comparability was based primarily on the procedural controls described above, while possible differences in teacher enactment, classroom climate, and school context remain limitations of the design.

3.3.4. Data Analysis

Analyses were selected to align with the study design and were conducted using SPSS, version 25. Descriptive statistics, including means and standard deviations, were calculated for all study variables. Before the intervention, baseline equivalence was examined using pretest scores. For achievement, a MANOVA was conducted on the three achievement dimensions, with the total test score reported descriptively because it is derived from the dimensions. For motivation, a MANOVA was conducted on the six motivation dimensions, with the total motivation score reported descriptively for the same reason. The analyses followed a baseline-equivalence approach rather than a covariate-adjusted ANCOVA model. Accordingly, posttest group comparisons were interpreted in conjunction with the pretest equivalence evidence, and the absence of pretest adjustment was considered when evaluating the strength of the findings. For posttest outcomes, dimension-level analyses and total-score analyses were interpreted separately to avoid treating total scores as independent of their subscales. Effect sizes were reported using eta squared (η^2). Before interpreting the models, normality was assessed by inspecting histograms and normal Q-Q plots of the outcome distributions and residuals; homogeneity of group variances was examined using Levene's tests; and homogeneity of variance-covariance matrices for the multivariate baseline analyses was assessed using Box's M. These diagnostic checks did not indicate substantial departures from the relevant distributional or variance assumptions. Independence, however, could not be fully satisfied at the individual student level because participants were nested within two intact classes; this dependence is treated explicitly as a design limitation. Given the small sample, intact-class structure, and multiple comparisons, dimension-level results were treated as theory-guided exploratory evidence rather than as stand-alone causal evidence. Statistical significance was set at $p < 0.05$.

4. Results

4.1. Baseline Equivalence Checks

To make the posttest analyses interpretable, pretest scores were examined to assess whether the experimental and control groups were broadly comparable at baseline. As shown in Table 3, the mean total achievement scores were 10.32 for the experimental group and 9.42 for the control group. The achievement dimensions did not differ significantly at baseline, Wilks' Lambda = 0.939, $F(3, 52) = 1.13$, $p = 0.346$. The motivation dimensions also did not differ significantly at baseline, Wilks' Lambda = 0.943, $F(6, 49) = 0.489$, $p = 0.807$. The multivariate baseline analysis for achievement was based on the three dimension scores—knowledge, application, and reasoning—rather than on the derived total score. Taken together, the measured pretest evidence supports broad baseline comparability between the two groups, although the use of intact classes means that unmeasured group differences cannot be completely excluded.

Table 3. Pretest descriptive statistics and baseline equivalence checks.

Measure	Dimension/Score	n per Group	Experimental M (SD)	Control M (SD)
Achievement	Knowledge	28	4.00 (1.00)	3.75 (1.33)
	Application	28	5.14 (1.34)	4.46 (1.33)
	Reasoning	28	1.18 (0.95)	1.21 (0.83)
	Total score	28	10.32 (2.83)	9.42 (1.95)
Motivation	Self-efficacy	28	3.56 (0.686)	3.64 (0.569)
	Active learning strategies	28	4.18 (0.487)	4.16 (0.360)
	Value of learning	28	4.13 (0.502)	4.20 (0.536)
	Performance goals	28	2.36 (0.929)	2.29 (0.704)
	Science achievement goals	28	4.47 (0.408)	4.48 (0.533)
	Stimulating learning environment	28	4.08 (0.567)	3.95 (0.760)
	Total score	28	3.86 (0.359)	3.86 (0.372)

Overall, the descriptive statistics and multivariate baseline analyses indicate that the two groups were broadly comparable before the intervention on the measured achievement and motivation variables. This baseline evidence supports the interpretation of the subsequent posttest comparisons, while recognizing that unmeasured differences related to school, classroom, or teacher factors cannot be entirely ruled out.

4.2. Academic Achievement

The first research question asked: What posttest differences in science achievement are observed between seventh-grade female students taught through the generative learning model and those taught through regular instruction? To address this question, the first null hypothesis stated that there is no statistically significant difference at the $\alpha = 0.05$ level between the mean posttest scores of the experimental and control groups on the academic achievement test.

After the baseline checks and completion of Unit Seven, *Living Organisms in Their Environment*, the academic achievement posttest was administered to both the experimental and control groups. Students' scores were entered into SPSS, and means and standard deviations were calculated for the total test score and its three dimensions: knowledge, application, and reasoning, according to instructional condition (generative learning model vs. regular instruction), as presented in Table 4.

Table 4. Means and standard deviations for the experimental and control groups on the posttest academic achievement measure.

Level	Number	Group	Mean	Standard Deviation
Knowledge	28	Experimental	5.78	1.39
Knowledge	28	Control	3.71	1.21
Application	28	Experimental	6.71	1.01
Application	28	Control	5.50	1.59
Reasoning	28	Experimental	2.32	1.09
Reasoning	28	Control	1.78	0.68
Whole test	28	Experimental	14.82	2.41
Whole test	28	Control	10.92	2.62

As shown in Table 4, the experimental group obtained higher posttest mean scores than the control group on the overall academic achievement test and across the three cognitive levels. This descriptive pattern indicates a consistent posttest advantage for students taught through the generative learning model, but it should be interpreted in light of the non-equivalent intact-class design.

To examine whether these posttest differences were statistically meaningful, the achievement dimensions were analyzed separately from the total achievement score, since the total score is derived from the dimension scores. This analytic separation addresses the statistical nonindependence between subscale scores and the total score.

Follow-up univariate analyses were conducted for each achievement dimension and for the total test score. The results of these analyses are reported in Table 5 and should be interpreted in light of the intact-class design and the absence of individual random assignment.

Table 5. Univariate analysis results for the posttest academic achievement scores by dimension and total score.

Source of Variation	Level	Sum of Squares	df	Mean Squares	F	p-Value	Effect Size
Group	Knowledge	60.07	1	60.07	35.09	<0.001 *	0.394
	Application	20.64	1	20.64	11.52	0.001 *	0.176
	Reasoning	4.01	1	4.01	4.84	0.032 *	0.082
	Whole test	212.16	1	212.16	33.30	<0.001 *	0.381
Error	Knowledge	92.42	54	1.71	—	—	—
	Application	96.70	54	1.79	—	—	—
	Reasoning	44.82	54	0.83	—	—	—
	As a whole	343.96	54	6.37	—	—	—
Total	Knowledge	1416.00	56	—	—	—	—
	Application	2206.00	56	—	—	—	—
	Reasoning	285.00	56	—	—	—	—
	Whole test	9839.00	56	—	—	—	—

Note. * indicates statistical significance at the 0.05 level ($p < 0.05$); — indicates not applicable. Effect sizes are reported as partial eta squared ($\eta^2 p$).

At the inferential level, the univariate analyses showed statistically significant differences between the experimental and control groups across all three dimensions of academic achievement, as well as for the total test score. Specifically, significant group differences were found for knowledge, $F(1, 54) = 35.09$, $p < 0.001$, $\eta^2 = 0.394$; application, $F(1, 54) = 11.52$, $p = 0.001$, $\eta^2 = 0.176$; reasoning, $F(1, 54) = 4.84$, $p = 0.032$, $\eta^2 = 0.082$; and the total achievement score, $F(1, 54) = 33.30$, $p < 0.001$, $\eta^2 = 0.381$. In all cases, the results favored the experimental group.

Taken together, these findings suggest that students taught through the generative learning model obtained higher posttest science achievement scores than students in the control group under the conditions of this study. Accordingly, the first null hypothesis was rejected, while the interpretation remains cautious because school, classroom, and teacher-related effects cannot be fully ruled out.

Discussion of Results Related to Students' Academic Achievement

In addition, the effect size estimates indicate meaningful posttest group differences in students' academic achievement. The effect was large for the total achievement score ($\eta^2 = 0.381$), as well as for the knowledge ($\eta^2 = 0.394$) and application ($\eta^2 = 0.176$) dimensions. However, the effect for reasoning ($\eta^2 = 0.082$) was moderate according to the classification reported by Abu Allam (2006), who described effect sizes of 0.01–0.06 as small, 0.07–0.14 as moderate, and values above 0.14 as large.

Taken together, the achievement results suggest that students who studied the unit *Living Organisms in Their Environment* through the generative learning model showed stronger posttest achievement at both the overall and subdimension levels. A plausible

explanation is that the model encouraged learners to activate prior knowledge, connect new content with existing understanding, and engage more actively with scientific concepts. These processes may have supported not only factual recall, but also students' ability to apply knowledge and reason through scientific ideas more effectively.

The pattern of stronger effects for knowledge and application may indicate that the model was especially effective in helping students organize and use newly learned content in meaningful ways. The more moderate effect on reasoning, while still statistically significant, may suggest that higher-order cognitive processes require longer exposure, more sustained practice, or additional forms of scaffolding beyond the duration of the present intervention.

Placed alongside previous research, these findings are consistent with studies in science education reporting positive effects of the generative learning model on academic achievement, including those of Adeyemi and Awolere (2016), Al-Otaibi (2020), Al-Saati (2023), Onanuga et al. (2020), and Yuliani et al. (2021). They are also consistent with studies conducted in other subject areas or educational contexts, such as Abdul Aziz (2020), Adak (2017), Basaffar (2017), Okeke and Okigbo (2021), and Ulusoy and Onen (2014), which reported that generative learning can support achievement, retention, conceptual understanding, or students' engagement. The present study extends this work by providing evidence from an Omani middle-school science classroom and by linking achievement gains to a model that also appears to support student motivation.

4.3. Motivation Toward Learning Science

The second research question asked: What posttest differences in motivation toward learning science are observed between seventh-grade female students taught through the generative learning model and those taught through regular instruction? To address this question, the second null hypothesis stated that there is no statistically significant difference at the $\alpha = 0.05$ level between the mean posttest scores of the experimental and control groups on the motivation toward learning science scale.

After completion of the same unit, the motivation toward learning science scale was administered to both the experimental and control groups. Means and standard deviations were then calculated for the total scale score and for its six dimensions: self-efficacy, active learning strategies, value of learning, performance goals, science achievement goals, and stimulating learning environment, as shown in Table 6.

As shown in Table 6, the experimental group obtained higher mean scores than the control group on the overall motivation scale and across all six dimensions. This descriptive pattern indicates a consistent advantage for students who were taught using the generative learning model.

To examine whether these differences were statistically meaningful, statistical tests were conducted separately for each motivation dimension and for the total motivation score, since the total score is derived from the six dimension scores. This approach avoided treating the total score as statistically independent of its component dimensions.

Follow-up univariate analyses were conducted for each dimension of the motivation scale and for the total score, with the total score interpreted separately from the dimension-level pattern. These results are shown in Table 7.

At the inferential level, the univariate results showed statistically significant differences between the experimental and control groups on five of the six motivation dimensions, as well as on the total score, in favor of the experimental group. Specifically, significant group differences were found for self-efficacy, $F(1, 54) = 16.45, p < 0.001, \eta^2 = 0.234$; active learning strategies, $F(1, 54) = 14.10, p < 0.001, \eta^2 = 0.207$; value of learning, $F(1, 54) = 10.00, p = 0.003, \eta^2 = 0.156$; performance goals, $F(1, 54) = 19.60, p < 0.001, \eta^2 = 0.266$; stimulating

learning environment, $F(1, 54) = 6.89$, $p = 0.010$, $\eta^2 = 0.113$; and the total motivation score, $F(1, 54) = 28.78$, $p < 0.001$, $\eta^2 = 0.348$. The result for science achievement goals was $F(1, 54) = 3.75$, $p = 0.058$, $\eta^2 = 0.070$. Because 0.058 exceeds the conventional 0.05 threshold, this dimension was interpreted as non-significant.

Table 6. Means and standard deviations for the experimental and control groups on the posttest motivation toward learning science scale.

Axis	Number	Group	Mean	Standard Deviation
Self-efficacy	28	Experimental	4.21	0.501
Self-efficacy	28	Control	3.59	0.638
Active learning strategies	28	Experimental	4.39	0.431
Active learning strategies	28	Control	3.91	0.516
Value of learning	28	Experimental	4.37	0.574
Value of learning	28	Control	3.71	0.951
Performance goals	28	Experimental	3.81	0.909
Performance goals	28	Control	2.86	0.679
Science achievement goals	28	Experimental	4.72	0.262
Science achievement goals	28	Control	4.48	0.587
Stimulating learning environment	28	Experimental	4.09	0.621
Stimulating learning environment	28	Control	3.57	0.853
Whole scale	28	Experimental	4.26	0.350
Whole scale	28	Control	3.69	0.440

Table 7. Follow-up univariate analysis results for the motivation toward learning science scores by dimension and total score.

Source of Variation	Axes	Sum of Squares	df	Mean Square	F	p-Value	Effect Size
Group	Self-efficacy	5.42	1	5.42	16.45	<0.001 *	0.234
	Active learning strategies	3.19	1	3.19	14.10	<0.001 *	0.207
	Value of learning	6.17	1	6.17	10.00	0.003 *	0.156
	Performance goals	12.63	1	12.63	19.60	<0.001 *	0.266
	Science achievement goals	0.78	1	0.78	3.75	0.058	0.070
	Stimulating learning environment	3.84	1	3.84	6.89	0.010 *	0.113
	Whole scale	4.55	1	4.55	28.78	<0.001 *	0.348
Error	Self-efficacy	17.80	54	0.33	—	—	—
	Active learning strategies	12.22	54	0.22	—	—	—
	Value of learning	33.34	54	0.61	—	—	—
	Performance goals	34.79	54	0.64	—	—	—
	Science achievement goals	11.18	54	0.21	—	—	—
	Stimulating learning environment	30.10	54	0.55	—	—	—
	Whole scale	8.45	54	0.158	—	—	—
Total	Self-efficacy	867.32	56	—	—	—	—
	Active learning strategies	983.82	56	—	—	—	—
	Value of learning	956.44	56	—	—	—	—
	Performance goals	671.88	56	—	—	—	—
	Science achievement goals	11,989.76	56	—	—	—	—
	Stimulating learning environment	856.83	56	—	—	—	—
	Whole scale	901.57	56	—	—	—	—

Note. * Statistically significant at $p < 0.05$. The science achievement goals result was $p = 0.058$ and was not statistically significant. Effect size is reported for the group effect only.

Taken together, under the conditions of this study, these findings suggest that students taught through the generative learning model reported higher overall motivation toward learning science than students in the control group. Accordingly, the second null hypothesis was rejected for the overall motivation score and for five motivation dimensions; it was retained for the science achievement goals dimension because the group difference was not statistically significant ($p = 0.058$).

Discussion of Results Related to Students' Motivation to Learn Science

In addition, the effect size estimates indicate meaningful posttest group differences in students' motivation toward learning science. The overall effect on the total motivation score was large ($\eta^2 = 0.348$). At the dimension level, the effects were also large for self-efficacy ($\eta^2 = 0.234$), active learning strategies ($\eta^2 = 0.207$), value of learning ($\eta^2 = 0.156$), and performance goals ($\eta^2 = 0.266$), and moderate for stimulating learning environment ($\eta^2 = 0.113$). The effect for science achievement goals ($\eta^2 = 0.070$) was moderate in magnitude but was not statistically significant at $p < 0.05$.

When viewed as a whole, the motivation results suggest that students in the generative learning group reported higher motivation toward learning science than those in the control group. A plausible explanation is that the model created more engaging learning conditions by encouraging students to connect prior knowledge with new ideas, participate actively in classroom tasks, discuss scientific concepts with peers, and assume a more central role in the learning process. Such experiences may have strengthened students' confidence, increased their sense of involvement, and improved their perceptions of the value of learning science. This interpretation remains tentative because self-report motivation scores may also be influenced by novelty, teacher interaction, and classroom climate.

The stronger effects observed for self-efficacy, active learning strategies, performance goals, and perceived learning environment may indicate that the model was particularly supportive of students' confidence, involvement, and perceptions of the classroom climate. The non-significant result for science achievement goals suggests that this aspect of motivation may develop more gradually and may require longer-term instructional exposure to show clearer differences.

Placed alongside previous research in science education, these findings are consistent with studies by Appiah-Twumasi (2019) and Kamil (2022), which reported positive effects of the generative learning model on students' motivation. They are also in line with findings reported in the broader educational literature, such as Latif Al-Samarrai and Saleh (2018) and Abdel-Ghani (2022), which reported positive associations between generative learning and students' learning outcomes in other subject areas. Together, the results add context-specific evidence from Oman that generative learning may be a useful way to enhance motivational dimensions directly relevant to science learning, including self-efficacy, active learning strategies, perceived value of science, and perceptions of the learning environment.

At the same time, a balanced interpretation is necessary because the quasi-experimental design cannot completely exclude alternative explanations. Differences between schools, teachers, classroom climate, students' prior experiences, novelty effects, or students' response tendencies on the self-report motivation scale may have contributed to the observed posttest pattern. Accordingly, future research should address these possibilities through larger samples, cluster randomization where feasible, teacher counterbalancing, stronger fidelity observation, and mixed-methods evidence that documents how students experience generative learning in the classroom.

5. Conclusions

In summary, the present study examined whether seventh-grade female students who were taught through the generative learning model showed higher posttest science achievement and motivation toward learning science than students who received regular instruction. The findings showed that the experimental group obtained higher posttest scores on the total achievement measure and across the achievement dimensions. The results also showed higher scores for the experimental group on the total motivation scale and on five of its six dimensions, while no statistically significant group difference was found for the science achievement goals dimension.

Viewed cautiously, these results provide preliminary evidence that the generative learning model may be associated with stronger science achievement and motivation in the specific context of this study. The model appeared to offer a structured way to encourage prior knowledge activation, explanation, application, and reflection within a regular science unit. However, the findings should be generalized with caution, as the study involved 56 female students from two schools, two different teachers, one science unit, and a limited implementation period.

Thus, the main contribution of the study is not a definitive causal claim about the general effectiveness of generative learning, but rather context-specific quasi-experimental evidence from Oman suggesting that generative learning may support academic achievement and motivation together. This contribution is important because science learning in middle school depends not only on students' acquisition of content knowledge, but also on their confidence, participation, perceived value of learning, and willingness to remain engaged with challenging scientific ideas.

At the practical level, the model may offer science teachers a structured sequence for moving students from prior knowledge activation to explanation, application, and reflection within regular curriculum units. At the research level, the findings point to the need for larger studies that include different governorates, male and female students, longer implementation periods, stronger fidelity measures, and analyses that control more fully for pretest scores, teacher effects, and school-level variation.

6. Limitations and Suggestions for Future Research

Several limitations should therefore be acknowledged when interpreting the findings of this study. First, because intact classes were used, students were not individually randomized to conditions; therefore, selection bias cannot be ruled out completely despite the use of pretest checks and procedures to improve group comparability. Second, the posttest analyses did not control for pretest scores through ANCOVA because the analysis used baseline equivalence checks rather than a covariate-adjusted model. Third, the study was conducted with a relatively small sample of 56 seventh-grade female students drawn from two schools, which may limit the generalizability of the findings to other grade levels, male students, or different educational contexts.

Taken together, these limitations mean that the results should be interpreted as preliminary and context-bound. In particular, the treatment condition was confounded with school, classroom, and teacher factors because each condition was implemented in only one intact class. The study therefore cannot determine whether the observed differences were due solely to the generative learning model. The absence of a full pretest-adjusted model, such as ANCOVA or multilevel modeling, also limits the strength of causal inference. For this reason, the conclusion is framed in terms of association and context-specific evidence rather than generalized causal effectiveness.

In light of these limitations, several directions for future research are recommended. Future studies could examine the effectiveness of the generative learning model with

larger and more diverse samples, including students from different grade levels, subject areas, school contexts, and governorates. Further research could use randomized or cluster-randomized designs where feasible, include independent observation-based fidelity measures, and apply covariate or multilevel analyses to account more fully for pre-existing differences and teacher or school effects. Longitudinal research could also investigate the long-term effects of the model on retention, transfer of learning, and sustained motivation. In addition, qualitative or mixed-methods studies may provide deeper insight into how students experience generative learning in science classrooms and which aspects of the model are most strongly associated with changes in motivation and achievement. Finally, future research could compare the generative learning model with other constructivist or inquiry-based approaches or examine its integration with digital tools and contemporary science teaching practices.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/educsci16071133/s1>, Section S1: Achievement Test in Science; Section S2: Science Learning Motivation Scale.

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