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Review Article

Contextualizing Genetics: A Meta-Analysis of Academic Achievement through Context-Based Teaching

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Abstract
This meta-analysis investigates the effectiveness of context-based teaching approaches on students' academic achievement in genetics, a subject often perceived by learners as abstract and cognitively challenging. Traditional instruction in genetics tends to emphasize memorization over meaningful understanding, contributing to widespread disengagement and underperformance. In response, educational reform efforts have increasingly promoted context-based teaching, which situates learning within real-world scenarios to improve relevance, comprehension, and learner motivation. The objective of this study was to quantify the impact of context-based instruction on academic achievement in genetics by synthesizing data from 69 master's and doctoral theses conducted between 2010 and 2022. These studies were selected based on stringent inclusion criteria: use of experimental or quasi-experimental designs, focus on genetics education, availability of relevant statistical data, and application of context-based instructional strategies. A total sample of 4,790 students was analyzed, 2,476 in experimental groups and 2,314 in control groups. Effect sizes were calculated using Comprehensive Meta-Analysis (CMA) software, applying both fixed-effect and random-effect models. The results demonstrated large and statistically significant positive effects of context-based instruction on student achievement in genetics (FEM $d = 0.789$; REM $d = 1.064$), with substantial heterogeneity observed across studies. These findings underscore the pedagogical value of integrating real-life contexts into genetics education. The study concludes that context-based instruction significantly enhances students' understanding and performance in genetics. It highlights the need for teacher training, curriculum reform, and instructional design that aligns with constructivist principles. While limitations exist, such as the exclusive reliance on theses and language restrictions, the study provides a strong foundation for future research and evidence-based policy in science education.

Keywords: Context-Based Teaching, Conventional Approach, Genetics, Science Education

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1. INTRODUCTION

Since the 2004–2005 school year, Ghana's Ministry of Education (MoE) has increasingly encouraged teaching approaches that reflect constructivist thinking, largely because learners differ in how they understand, process, and apply knowledge. At the heart of constructivism is a simple idea: students do not "receive" knowledge as finished facts; instead, they build new understanding by connecting fresh information to what they already know (Unal & Akpinar, 2006). In this view, learning involves making sense of new ideas, noticing when they clash with prior beliefs, and adjusting one's thinking to accommodate the new understanding.

Yet, in many classrooms, science still struggles to attract students. Despite its relevance to modern life, students often show limited interest in science and may even feel disconnected from it (Centre for Development and Enterprise [CDE], 2010). One major reason is how science is commonly taught: as memorisation of abstract facts and difficult concepts that appear to have little meaning beyond the classroom. This approach conflicts with the natural, experience-driven way young people learn about the world through curiosity, interaction, and problem-solving in real settings (Onwu et. al., 2011). In addition, teachers and broader science education systems sometimes do not communicate science as a tool for solving real human problems and improving society, which can further reduce learners' motivation (Onwu & Kyle, 2011; Sadler, 2009).

Another challenge is the weak connection between what students learn in science lessons and what they experience every day. When teaching strategies do not deliberately link classroom concepts to practical experiences, students are more likely to see science as distant and irrelevant (Dube & Lubben, 2011). For this reason, many science educators worldwide have turned to context-based teaching approaches to make science learning more meaningful, engaging, and applicable (Bennett & Holman, 2002; Gilbert et al., 2011). The central aim of context-based science education is to help learners understand scientific ideas by presenting them through situations they recognize, which show *why* the concept matters and *where* it is used (Gilbert et al., 2011). In other words, instead of teaching ideas first and hoping students later see their value, context-based approaches use real-life applications and student-familiar scenarios to make content more accessible and easier to understand (Bennett & Holman, 2002; Dube & Lubben, 2011; Gilbert et al., 2011).

More recently, context-based teaching has also been used to shift science learning away from simply "knowing facts" toward deeper scientific practices such as designing investigations, constructing arguments, and engaging in critical discussion (Krajcik, McNeill, & Reiser, 2008). Although "context" is defined in many ways, ranging from environmental and health issues to community and industrial applications, most definitions share two important ideas: learning is situated, and learning becomes stronger when it relates to students' real experiences (Bennett, 2003; Whitelegg & Parry, 1999). For example, the Queensland Studies Authority describes context as learning activities that motivate students to apply key ideas to real-world situations (Queensland Studies Authority, 2004). Similarly, Baker, O'Neil, and Linn (1994) emphasise learning tasks that feel meaningful from the learner's perspective. In this study, context-based teaching is therefore understood as science instruction that develops students' knowledge and skills using real-life situations they already know, consider relevant, and can connect with.

This perspective also aligns with arguments that science classrooms should support meaningful learning by encouraging active exploration of issues that matter socially and personally, helping students feel empowered and engaged rather than passive (Bennett & Holman, 2002; Roth & Lee, 2004; Sadler, 2009). With these ideas in mind, this study seeks to determine whether context-based science teaching is more effective than conventional approaches (traditional, teacher-centred methods) in two key areas: (a) improving students' achievement in genetics and (b) producing stronger learning outcomes than the conventional method.

Genetics was selected because it is widely described as conceptually demanding and difficult for many learners (Dairianathan & Subramaniam, 2011; Furberg & Arnseth, 2009; Knight & Smith, 2010). Beyond the classroom, genetics and the wider biological sciences are increasingly important for understanding and responding to major societal challenges such as food security, malnutrition, environmental degradation, and access to clean water and sanitation issues that strongly shape sustainable development discussions across Africa, including Ghana. However, Ghanaian students' performance in the biological sciences has not been consistently strong, and evidence suggests that life science topics such as genetics continue to challenge both teachers and students (Ministry of Education, 2009; Chief Examiners' Reports, 2018, 2019, 2020, 2021).

Research supports these concerns. Studies have shown that students' difficulties in genetics are often linked to weak conceptual understanding, limited ability to apply ideas through reasoning, and the perception that genetics has little relevance to everyday life (Dogru-Atay & Tekkaya, 2008; Ibanez-Orcajo & Martinez-Aznar, 2005; Lewis & Kattman, 2004). Because Ghana's updated life sciences curriculum encourages the use of real-world scenarios, it becomes important to test whether a context-based approach can actually improve achievement in genetics more effectively than conventional teaching.

This need is even more pressing because learning difficulties in science have frequently been associated with ineffective teaching approaches (Makgato & Mji, 2006; Wilke, 2003). Although evidence on context-based and Science-Technology-Society (STS) approaches is mixed in terms of purely cognitive outcomes, studies have reported positive effects on motivation and engagement outcomes that are often necessary for sustained improvement in learning (Bennett et al., 2007). At the same time, the varied findings may reflect differences in the contexts used, the quality of the learning materials, and how teachers implement the approach in real classrooms (De Jong, 2008; Gilbert, 2006). This study is therefore designed to add to the evidence by examining whether, and to what extent, context-based teaching can strengthen students' achievement in genetics in comparison with conventional teaching methods.

Table 1. Meta-Analysis Research Studies in the Field of Education

Researchers	Subject of Research	Effect Size Value	Effect Size Level*
Taicon (2016)	Environment in science	1.009	Large Level
De Jong (2008)	Chemical Education	1.245	Very Large
Esra, Figen, and Erzurun (2014)	Attitude in Biology	0.973	Large Level
Brista and Ustunel (2012)	Attitude and confidence	0.849	Large Level
Donna King and Stephen (2014)	Demonstrating fluid transition	0.816	Large Level
Ceyhan, Higde, and Geban (2016)	Chemical Reactions	1.029	Large Level
Gjalt(2018)	Scientific modelling	1.130	Very Large
Robert and Tim (2010)	Learning for Beginners	0.831	Large Level
Gebeyaw (2022)	Achievement in Physics	1.206	Very Large
Kazeni (2012)	Performance in Life Science	1.255	Very Large

In accordance with the classification of Thalheimer and Cook (2002)

There is still limited research evidence, especially in the form of meta-analyses, that clearly shows how context-based learning influences students' academic achievement. Because of this gap, this study is expected to make a meaningful contribution to the existing literature. The main purpose of the study was to use a meta-analysis to determine the overall effect of a context-based instructional approach on students' academic performance. In simple terms, the study brings together results from multiple studies to answer one central question:

To address this broad question more carefully, the meta-analysis was guided by the following specific issues:

- Does context-based teaching improve students' academic performance?
- Does the type of dissertation (for example, undergraduate, master's, or PhD research) influence how well students perform when taught using a context-based approach?
- Do students' educational backgrounds influence how well they achieve when learning through a context-based approach?

1.1. Literature Review

Many countries are now trying to strengthen science education by creating learning environments that are more lively, relevant, and responsive to the needs of students and society. One major way they are doing this is by experimenting with context-based teaching approaches that start from real-life situations and then connect learners to the science behind them (Osbourn & Dillon, 2008). This approach has attracted attention because it speaks directly to several long-standing concerns about how science is taught around the world (Lyons, 2006).

A common complaint is that school science often feels like a collection of isolated facts and abstract theories that students struggle to connect to real life (Gilbert, 2006). When learners cannot see the value of what they are studying or when the content appears too difficult and "far from their world," they may become frustrated, lose interest, and eventually disengage from science lessons altogether. These criticisms have pushed many science educators and researchers to look for better ways of teaching that make science more meaningful and enjoyable (De Jong, 2008; Meijer et al., 2013; Millar, 2007; Roehrig et al., 2007; Sevian & Bulte, 2015; Sevian & Talanquer, 2014; Sjöström & Talanquer, 2014).

Although "context-based instruction" can mean different things in different places, the basic idea is consistent: it begins with the *context,* the real-world use, problem, or situation, and then draws students into the scientific concepts needed to understand or solve it. Bennett et al. (2007) describe it as an approach that starts from the contexts and applications of science. In practice, context-based teaching uses science to help students make sense of real-life problems and to develop the ability to act responsibly and thoughtfully as members of society (Aikenhead, 2006; Bennett, 2005; Beatty & Schweingruber, 2017; King, 2012).

A key principle behind this approach is what researchers call the "need-to-know" principle. This simply means that students are more willing to learn scientific ideas when they feel those ideas are *needed* to understand something real and important in their lives (Pilot & Bulte, 2006; King, 2012). Instead of presenting science content first and adding examples later, context-based learning introduces a real problem or situation upfront, and then the science becomes the tool students use to explain what is happening. Real-world issues are turned into meaningful classroom tasks that help students build knowledge and skills in ways that feel purposeful (Baker et al., 1994).

In this study, context-based education is therefore understood as teaching scientific ideas and skills through practical, familiar applications. The assumption is that real-life scenarios give "meaning" to scientific theories, helping students move beyond memorising facts to a deeper understanding (Stolk et. al., 2012). When students explore science through situations they recognize, such as health issues, environmental problems, local community needs, or everyday experiences, they are more likely to stay engaged and to understand the concepts more clearly.

Researchers argue that science education becomes more valuable when students are exposed to authentic situations that reflect the real world and challenge them to think (Gilbert et al., 2011). For context-based learning to work well, the context must not be random; it has to be meaningful and familiar to students. Gilbert (2006) explains that the context should provide a clear structure that helps learners understand something new by placing it within a broader situation they can recognise. In other words, the setting should "make sense" to students and connect naturally to their prior knowledge.

Good contexts can come from everyday life experiences, social debates, community challenges, or real scientific practices, anything students can relate to and find important (Gilbert, 2006). In addition, context-based learning often encourages greater student choice, collaboration, discussion, and engagement with how science is done, not just what science says. However, for this to succeed, the classroom environment must be supportive and well-managed, allowing productive conversation, creativity, and shared meaning-making (Gilbert et al., 2011). Ultimately, context-based teaching aims to help students understand their world using science, and to see science not as distant theory, but as a useful way of thinking and solving problems in everyday life.

2. METHODS

2.1. Research Model

The study employed meta-analysis to assess context-based learning's efficacy in the classroom. In order to determine how the independent variable influences the dependent variable, Cohen et al. (2007) describe meta-analysis as the process of analyzing, measuring, and integrating quantitative data from experimental and quasi-experimental investigations. Meta-analyses fall into two categories: correlation and group comparison. Among the group comparison meta-analysis techniques included in this study is the transaction efficacy meta-analysis. In a transaction effectiveness meta-analysis, data from several studies that were used in numerous studies are combined into a single measurement system to evaluate impact size estimations.

2.2. Collection of Data

PhD and master's theses having the required quantitative data on the published statistical evaluation conducted using the context-based technique in the national education process between 2010 and 2022 are included in the research. The terms "academic achievement" and "context-based approach" were screened from English-language theses. Only 70 articles out of 90 papers satisfied the two requirements. Only 69 articles satisfied the remaining requirements following a thorough screening process that included full-text scanning. Snowball sampling was another effective search strategy, according to Greenhalgh and Peacock (2005). No further publications that met the requirement were discovered by looking through the reference lists of the 69 articles. The main reason for this low figure was that academic accomplishment was not measured by many context-based publications.

2.3. Research Inclusion Requirements

1. The study was to be conducted in a context-based environment between 2010 and 2022

This period of time was selected because it represents an era of pedagogical change when context-based instruction became increasingly popular in scientific education studies. Notably, starting in 2010, academic publications (Gilbert et al., 2011) and educational reforms placed a greater emphasis on integrating constructivist learning, real-world settings, and student-centered techniques in scientific instruction. Additionally, most recent research conducted during this time period used strict experimental or quasi-experimental designs and reported effect estimates and statistical data more consistently, which is crucial for meta-analytic synthesis. As a result, the 2010–2022 window guarantees pedagogical relevance, methodological consistency, and conformity with the changing objectives of contemporary scientific education.

2. The study ought to be included in the national master's and doctoral theses

In-depth methodological information, unprocessed data, and statistical results (means, standard deviations, effect sizes) that are occasionally absent or simplified in journal articles are frequently included in theses. In meta-analytic calculations, where accurate data extraction is crucial, this level of detail is very helpful. This study's goal was to compile studies from national educational environments. Local university theses frequently highlight curricular implementations, classroom dynamics, and context-specific teaching methods that might not be covered in more general international publications. This made it possible to analyze context-based instruction in the local or regional educational system in a more representative and focused manner.

3. Employing experimental or quasi-experimental research techniques

4. Analyzing the study participants' academic performance

5. Outlining the statistical information required to determine the study's effect size

2.4. Data Coding

To make it possible to compare the different studies fairly, decide which ones were suitable for inclusion in the meta-analysis, and clearly capture the statistical information needed for analysis, the researcher developed a well-structured coding form. This form served as a guide for extracting the same type of information from every study, so that all selected studies could be evaluated using a consistent standard.

The coding form captured key quantitative details from each study in an organised way. Specifically, information was recorded under headings such as the study title/name, type of study, intended learning outcomes, discipline/subject area, year of publication, participants' educational level, and the statistical data reported (for example, sample size, means, standard deviations, test statistics, and other relevant results). This systematic approach ensured that the data needed for the meta-analysis were complete, comparable, and reliable.

2.5. Analysis of Data

Effect sizes for the studies were calculated using the Comprehensive Meta-Analysis (CMA) software developed by Biostat (www.meta-analysis.com). In addition to estimating the overall effect, the study also conducted a moderator analysis to examine whether the results differed across categories or subgroups, and to understand the possible sources of variation in the average effect sizes.

To compute each effect size, the study used the standardized mean difference (*d*). This was done by taking the difference between the mean scores of the experimental and control groups and then dividing that difference by the standard deviation, following the approach described by Hedges and Olkin (1986). Because the main outcome of interest was academic performance, only effect sizes related to students' achievement were calculated. Where a study measured achievement using more than one test or assessment, the researcher avoided treating these as separate independent results. Instead, the effect sizes from the different assessments were combined into one representative value by averaging them. This ensured that each study contributed only one effect size to the meta-analysis, making the overall findings more balanced and avoiding over-representing any single study.

2.6. Limitations and Potential Biases

While the inclusion of only doctoral and master's theses provided access to rich, detailed datasets often unavailable in journal articles, this decision introduces certain limitations and potential biases. First, these are not always subjected to the same rigorous peer-review processes as published journal articles, which may affect the overall quality and reliability of the included studies. Second, the academic standards and supervision quality can vary significantly across institutions, leading to inconsistencies in research design, implementation, and reporting. Third, by excluding peer-reviewed articles and conference proceedings, the analysis may have missed high-quality and influential studies that could offer additional insights or comparative results. Finally, there is a risk of institutional or regional bias, as most theses tend to originate from specific geographic or academic contexts, potentially limiting the generalizability of the findings. These limitations suggest that the results, while meaningful, should be interpreted with caution and complemented by future research that incorporates a broader range of scholarly sources.

3. FINDINGS

In this study, effect sizes were calculated from 69 dissertations included in the meta-analysis. Out of these, 49 effect sizes came from master's theses, while 20 effect sizes were drawn from doctoral dissertations. Altogether, the studies involved a large number of learners: 2,476 students were in the experimental groups (those taught using the context-based approach), and 2,314 students were in the control groups (those taught using the conventional method).

Table 2. Results of Studies on the Impact Sizes of Academic Achievement

Model	N	ES	df	(Q)	Std. Error	Z	p	I^2	% 95 Confident Lower Limit	Level Upper Limit
Fixed	69	0.789	68	25.961	.021	8.402	.001	65.539	0.954	1.142
Random	69	1.064			.071	6.441	.001		1.025	1.303

Using the fixed-effect model (FEM), the analysis assumes that all 69 studies are basically estimating one true common effect, and that any differences we see are mostly due to sampling error. Under this model, the combined (pooled) effect size was reported as ES = 0.789, suggesting that context-based teaching improves achievement. However, the results also show that the studies do not line up neatly with one another: Cochran's Q = 25.961 ($p = 0.001$) indicates statistically significant differences between study results, and the heterogeneity estimate suggests that about 65.5% of the variation is due to real differences across studies rather than chance. The FEM output also reported Z = 8.402, SE = 0.021, and a 95% CI of 0.954 to 1.142, implying the overall effect is statistically significant.

Because the studies show clear variation, the random-effects model (REM) is more appropriate. The REM accepts that studies may be estimating slightly different true effects (for example, because of differences in students, school settings, topics, duration of intervention, or research design). Under the REM, the pooled effect size was ES = 1.064, which Thalheimer and Cook's (2002) guide would describe as a very large impact. As expected, the REM produces a larger standard error (SE = 0.071) because it accounts for between-study differences. Even with that added uncertainty, the effect remains highly significant (Z = 6.441, $p = 0.001$), and the 95% CI (1.025 to 1.303) still sits well above zero, meaning the improvement is unlikely to be due to chance.

Overall, these findings tell a clear story: context-based teaching significantly improves students' academic achievement, and the fact that the studies vary substantially suggests that the size of the benefit may depend on factors such as the learning context used, student characteristics, and how the approach was implemented.

4. DISCUSSION

The findings from this meta-analysis affirm the significant impact of context-based teaching approaches on students' academic achievement in genetics. The pooled effect sizes $d = 0.789$ under the fixed-effect model and $d = 1.064$ under the random-effect model indicate that these approaches lead to large and very large improvements in academic performance. These results are in line with studies like De Jong (2008), who reviewed context-based chemistry education and found that such approaches generally produce positive learning outcomes, though effectiveness can vary by implementation strategy and context. Similarly, Gilbert et al. (2011) emphasized that context-based education enhances student engagement by linking scientific content to real-world scenarios that are personally meaningful to learners.

The effect sizes appear slightly higher than the general range reported by Bennett et al. (2007), who noted positive but more moderate effect sizes. This may be due to the specific focus on genetics, a notoriously abstract and difficult subject where context-based methods may have a particularly strong benefit. The nature of the primary sources used (i.e., doctoral and master's theses) may also have influenced the larger observed effect sizes, as these studies often involve more detailed interventions and in-depth data collection.

Nevertheless, the observed heterogeneity among studies ($I^2 = 65.5\%$) indicates that factors such as education level, instructional design, and implementation fidelity likely influence the effectiveness of context-based teaching. These findings contribute to the existing literature by offering discipline-specific evidence of the benefits of contextualized instruction specifically in genetics education, an area that has received limited meta-analytic attention.

5. CONCLUSION AND IMPLICATIONS

This meta-analysis examined the impact of context-based teaching strategies on students' academic performance in genetics, a topic that is frequently seen as challenging and abstract. The study, which included 4,790 students (2,476 in experimental groups and 2,314 in control groups), included data from 69 master's and doctoral theses published between 2010 and 2022. Using strict inclusion criteria and coding processes, the search concentrated on theses that included quantitative data on academic attainment and context-based education. The Comprehensive Meta-Analysis (CMA) program was used to calculate effect sizes using both fixed-effect and random-effect models. Context-based education significantly enhances students' academic performance in genetics, according to the results, which showed statistically significant and substantial to very large impact sizes ($d = 0.789$ and $d = 1.064$, respectively).

Despite these encouraging outcomes, a number of limitations were noted. The study only used theses, which may not have the same rigorous peer review as journal papers, while being rich in data. This raises possible questions about the quality of the study and methodological consistency. Incorporating gray literature also reduced publication bias, but at the expense of excluding peer-reviewed journal articles and conference papers that may have provided more comprehensive viewpoints. Additionally, the search was restricted to English-language publications, which may have left out pertinent research in other languages. These elements could restrict how broadly the results can be applied.

Practically speaking, the findings highlight how important it is to match science education with students' real-world experiences. By integrating learning into socially and personally meaningful situations, educators may use context-based techniques to improve genetics engagement, understanding, and retention. Curriculum designers are urged to provide adaptable resources that incorporate genetically connected socioeconomic and environmental concerns, such as health, biotechnology, and agriculture. The results emphasize the necessity for policymakers and teacher training institutions to fund professional development initiatives that provide educators with the pedagogical know-how to successfully apply context-based techniques.

This work adds fresh empirical data to the junction of genetics teaching and context-based learning, an area of scientific education that has received little attention. Few meta-analyses have examined the use of context-based approaches in genetics, despite the fact that they have been investigated in other scientific fields. As a result, our study closes a significant gap and offers a quantitative basis for influencing future research, instructional design, and policy choices.

Future research should broaden its focus to include peer-reviewed literature, carry out long-term studies into the long-term effects of context-based instruction, and assess its efficacy in various geographical and sociocultural contexts. The findings from this meta-analysis can guide the creation of an inclusive, student-centered curriculum that promotes deeper comprehension, critical thinking, and practical problem-solving abilities in an era of evidence-based education reform, especially in challenging areas like genetics.

6. RECOMMENDATIONS

1. Curriculum developers should incorporate context-based teaching strategies across all education levels, focusing on real-world applications to improve student engagement and comprehension (Bennett et al., 2007).
2. Teachers should be equipped with the skills to design and implement context-based learning activities. Training programs should focus on helping educators connect academic content to students' everyday lives (Gilbert et al., 2011).
3. Context-based approaches should be tailored to account for cultural, social, and institutional factors, ensuring that they meet the unique needs of different learner groups (De Jong, 2008).
4. Future studies should examine the moderating factors influencing the variability of effect sizes, such as educational level, geographical location, and subject area. Longitudinal studies are also recommended to explore the long-term impact of context-based teaching on academic achievement (Makgato & Mji, 2006).

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Research Ethics. This study is a meta-analysis that synthesized findings from previously conducted and publicly available master's and doctoral theses. As such, it did not involve direct interaction with human participants, nor did it collect new data from individuals. All data analyzed were secondary and already anonymized within the original studies. Because the research relied solely on existing, published academic work that had already undergone ethical review at their respective institutions, there was no requirement for a separate ethical clearance for this meta-analysis. This approach aligns with standard academic practices and international guidelines for secondary data analysis, which typically exempt such studies from additional ethical approval.

Data Availability Statement. This study is based on secondary data from published master's and doctoral theses (2010–2022). No new data were generated; materials are available from the corresponding author upon reasonable request.

Conflicts of Interest. The authors declare no conflicts of interest.

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