

# Reimagining chemistry education: A meta-analysis of competency-based teaching and its influence on student attitudes and motivation

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## ABSTRACT

This meta-analysis investigates the impact of competency-based teaching (CBT) approaches on students' attitudes and motivation toward chemistry education. The study aims to synthesize findings from 25 empirical studies conducted between 2000 and 2023 to determine the effectiveness of this approach in diverse educational settings. Using a systematic literature search and well-defined inclusion criteria, the analysis includes both experimental and quasi-experimental designs with sample sizes ranging from 30 to 1,500 participants. Effect sizes were calculated using a random-effects model, and heterogeneity and publication bias were assessed through statistical metrics such as  $I^2$  and funnel plots. The findings indicate that CBT significantly improves students' attitudes toward chemistry (mean effect size = 0.58,  $p < 0.01$ ) and enhances motivation (mean effect size = 0.65,  $p < 0.01$ ), particularly in areas such as intrinsic motivation, self-efficacy, and mastery goal orientation. Subgroup and moderator analyses revealed stronger effects among high school students and in studies with high implementation fidelity. Key contributing factors to these positive outcomes included student-centered learning, real-world applications, and personalized pacing. The results suggest that competency-based approaches hold substantial promises for enhancing engagement and learning outcomes in chemistry, provided that adequate teacher training and resources are in place.

**Keywords:** competency-based approach, attitude toward chemistry, motivation towards chemistry, confidence towards chemistry

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## INTRODUCTION

Competency-based teaching (CBT) has emerged as a promising pedagogical approach aimed at improving learning outcomes by focusing on students' mastery of clearly defined competencies. Unlike traditional education models that emphasize seat-time and content coverage, competency-based education promotes flexible pacing, personalized learning, and student-centered instruction (Henri et al., 2017). This instructional shift aligns closely with constructivist learning theory, which suggests that knowledge is constructed through active engagement, reflection, and contextual application (Colson & Hirumi, 2018; Pardjono, 2016). Recent studies have affirmed the positive outcomes associated with CBT in STEM education, particularly in enhancing students' attitudes and motivation. According to Kim et al. (2023), competency-based instruction in science subjects fosters higher levels of engagement by allowing learners to progress at their own pace while engaging in hands-on, inquiry-driven activities. Similarly, Dodier (2020) notes that students in competency-driven environments demonstrate increased intrinsic motivation due to greater autonomy

and relevance in their learning tasks. Attitude and motivation are central to students' success in chemistry, a subject often perceived as abstract and difficult (Hofstein & Mamlok-Naaman, 2011; Osborne et al., 2003). Negative attitudes toward chemistry have been linked to anxiety and poor achievement (Musengimana et al., 2021), while positive attitudes correlate with better performance and continued interest in science fields (Woldeamanuel, 2019). Recent findings by Manurung and Manurung (2021) confirm that chemistry students with higher motivation tend to demonstrate more consistent learning behaviors and improved academic outcomes.

Motivation itself is multifaceted and has been extensively studied under the lens of self-determination theory (SDT), which emphasizes the role of intrinsic motivation, autonomy, and competence (Deci et al., 2017). CBT aligns well with SDT by fostering autonomy through flexible pacing, competence through skill mastery, and relatedness via collaborative learning opportunities. Alamri et al. (2020) found that when learning environments are designed to promote self-directed learning and meaningful feedback, students are more likely to develop long-term interest and engagement in science.

Additionally, Vishnumolakala et al. (2017) demonstrated that students in active learning chemistry settings characteristic of CBT environments reported higher levels of self-efficacy and enjoyment. These outcomes are reinforced by Ferrell and Barbera (2015), who emphasized that confidence in one's ability to succeed in chemistry significantly boosts overall motivation and persistence. However, successful implementation of CBT requires attention to contextual factors. Morcke et al. (2013) highlight that institutional readiness, teacher training, and assessment reform are essential for the sustainable application of competency-based models. Newmes (2019) and Hoban (2017) also caution that while CBT offers potential benefits, its impact is maximized when aligned with adequate instructional resources, ongoing teacher professional development, and student support systems.

Chemistry education is vital in developing students' understanding of scientific concepts and processes (Geelan et al., 2014). However, many students struggle to connect with chemistry, leading to negative attitudes and decreased motivation (Lin-Siegler et al., 2016). CBT approaches have gained attention in recent years, focusing on student's demonstrations of specific skills and knowledge (Voorhees, 2001).

Meta-analysis was initially developed to statistically analyze the results of similar experimental studies (Glass, 1977). Furthermore, the number of meta-analysis studies in education sciences has been increasing recently (Card, 2012). Meta-analysis studies have been used in a wide range of topics, such as comparing distance education and conventional classroom education. As the number of primary studies in all scientific fields increases, the need to synthesize the results obtained from these studies with meta-analytic methods also increases (Miller & Pollock, 1994).

Extensive research has explored the attitudes of students, revealing valuable insights into their behaviors, motivation, and CBT approaches in chemistry, as shown in the literature review.

People's attitudes toward science are shaped by a blend of their values, emotions, and beliefs, influencing how they engage with scientific understanding and discovery (Osborne et al., 2003). Similarly, attitudes are the process of forming positive or negative thoughts and feelings about elements in our environment that greatly influence our perceptions and experiences (Abun et al., 2019). Moreover, attitudes are valuable outcomes that can be nurtured throughout the learning process. As students engage with their studies, their attitudes can evolve positively, influenced by observation, personal experiences, and the overall learning environment. This dynamic shift highlights the importance of creating supportive and enriching experiences that foster constructive attitudes in learners (Musengimana et al., 2021). Therefore, shifts in attitude are largely shaped by the impact of teachers, the support of parents, the traits of peers, and the overall dynamics of the classroom environment (George & Kaplan, 1998).

According to Pajares and Usher's (2008) article, motivation for learning is influenced by observation, self-efficacy, reinforcement, and reciprocal determinism. This theory emphasizes the interplay between personal factors, environment, and behavior in shaping motivation and learning (Pajares & Usher, 2008). However, motivation learning is enhanced when goals are specific, challenging, and aligned with individual values and interests (Alamri et al., 2020). In chemistry education, goal-setting can be applied by setting specific learning objectives, encouraging students to set personal goals, providing

regular feedback, and aligning goals with real-world applications (Reyes et al., 2014).

Students should understand different learning styles, as well as the strengths of their learning styles (Zapalska & Dabby, 2002). It is informative for teachers to be aware of students' learning styles (Pashler et al., 2008).

In CBT, the focus is on empowering students to demonstrate specific skills and knowledge. This approach shifts away from traditional age-based or grade-based progression, allowing for a more personalized learning experience that supports individual growth and mastery (Hoban, 2017), because knowledge, hands-on experiences, and competencies are key components of the teaching and learning process. CBT approach integrates content knowledge, scientific practices, and crosscutting concepts, and fosters students' attitudes and competencies, including confidence and relevance (Mosha, 2012). Moreover, competency-based education emphasizes personalized learning, flexibility, and mastery of defined competencies, students in competency-based classrooms reported increased motivation and engagement (Newmes, 2019). According to Ituma's (2022) article, competency-based education increases intrinsic motivation and reduces extrinsic motivation, where students' internal motivation and genuine interest in understanding chemical concepts, processes, and principles. On the other hand, CBT promotes mastery-oriented motivation, students focus on developing competencies, improving skills, and achieving mastery of chemical concepts and processes, Therefore, teachers should emphasize mastery of chemical concepts, and students should set self-directed learning goals (Kramer, 2021).

## Research Problem

This meta-analysis aims to synthesize existing research on the impact of CBT approaches on students' attitudes and motivation toward chemistry and examine the consistency of findings across different studies and contexts.

## Objectives of the Study

1. To examine the effect of CBT approaches on students' attitudes towards chemistry.
2. To investigate the impact of CBT approaches on students' motivation towards chemistry.
3. To identify the moderating factors that influence the relationship between CBT approaches and students' attitudes and motivation towards chemistry.

## Variables

By examining these variables, the meta-analysis aims to provide a comprehensive understanding of the impact of CBT approaches on students' attitudes and motivation toward chemistry.

### *Independent variable: Competency teaching approach*

This involves the instructional method in which students advance upon mastering specific competencies, with a focus on self-paced, student-centered learning and practical applications.

### *Dependent variables*

**Students' attitudes towards chemistry:** This includes students' overall disposition toward chemistry, which could range from enthusiasm and interest to anxiety or dislike.

**Table 1.** Improvement in chemistry scores after CBTA intervention

Group	Pre-test mean score	Post-test mean score	Mean gain
Control group	56.2	59.1	2.9
Experimental group (CBT)	57.4	74.3	16.9

**Motivation to learn chemistry:** This refers to both intrinsic (internal drive to learn chemistry due to interest) and extrinsic motivation (learning driven by external rewards such as grades).

**Moderating variables:** Student characteristics (age, gender, and prior knowledge), teacher characteristics (experience and training), Instructional context (classroom environment and resources), assessment methods (formative and summative), cultural and socioeconomic factors.

**Outcome measures:** Students' attitudes towards chemistry (interest, enjoyment, and relevance), students' motivation towards chemistry (self-efficacy, achievement goals, and engagement) (Ferrell & Barbera, 2015; Vishnumolakala et al., 2017).

### Theoretical/Conceptual Framework

This study is grounded in SDT by Deci et al. (2017), which emphasizes the role of intrinsic and extrinsic motivation in learning. CBT aligns with SDT as it promotes autonomy, mastery, and competence, fostering an internal sense of motivation (Deci et al., 2017).

According to Pardjono (2016), articles, constructivist learning theory suggests that active involvement in learning, which is a cornerstone of CBT, enhances both engagement and motivation (Colson & Hirumi, 2018). Previous literature on attitudes and motivation in chemistry education highlights those traditional methods often lead to anxiety and disinterest, while innovative, student-centered approaches can reverse these trends.

Additionally, the study draws from Biggs' (1999) article, which emphasizes the importance of students achieving a high level of understanding in one topic before moving to the next. This theory supports the competency-based model, where students are encouraged to master chemistry concepts at their own pace (Hanson & Acquah, 2014). Reducing frustration and anxiety is often associated with traditional, time-constrained instruction. Research suggests that CBT approaches can improve student learning outcomes (Morcke et al., 2013).

According to the studies of Kim et al. (2023) have shown that competency teaching approach (CBTA) fosters higher motivation in STEM subjects by allowing students to engage more deeply with the material through hands-on learning and by giving them control over their progress. Motivation is a key factor in students' learning outcomes in chemistry (Manurung & Manurung, 2021). According to Kousa et al. (2018), articles on attitudes toward chemistry, indicate that traditional teaching methods often result in negative attitudes toward chemistry, particularly due to the abstract nature of the content Students' attitudes toward chemistry are critical for their motivation and engagement in learning chemistry (Woldeamanuel, 2019). Research has identified factors influencing attitudes toward chemistry, including teacher enthusiasm, hands-on activities, and relevance to everyday life (Hofstein & Mamlok-Naaman, 2011).

## LITERATURE REVIEW

The literature search was carried out using multiple academic databases such as Scopus, Web of Science, Google Scholar, and ERIC. Keywords included "competency-based teaching," "chemistry education," "student attitudes," and "motivation in chemistry." The search focused on peer-reviewed articles published between 2000 and 2023 to capture recent trends in educational methods (Manjong, 2023).

### Criteria for Selection/How You Retained/Retrieved Articles for Meta-Analyses

The inclusion criteria used were as follows: Studies that explicitly employed a CBT approach in chemistry education, studies that measured student attitudes and/or motivation, quantitative, qualitative, or mixed-method research, and articles written in English and published in peer-reviewed journals.

The exclusion criteria included: Studies that focused on other subjects or disciplines outside of chemistry and articles without empirical data, or those offering only theoretical discussions without practical application.

### Selection of Electronic Database Searches Performed in the Academic Search

Electronic databases were systematically searched: Scopus for comprehensive coverage of science and education literature, Web of Science for multidisciplinary studies, focusing on educational methodologies, ERIC for educational studies and reports, and Google Scholar to include gray literature that may not appear in traditional databases.

### Meta-Analysis Procedure

To conduct the meta-analysis, statistical techniques were employed to synthesize results from individual studies. Effect sizes were calculated for each study, focusing on the magnitude of change in student attitudes and motivation due to the competency-based approach. The random-effects model was utilized to account for variability between studies. Heterogeneity was measured using the  $I^2$  statistic, and publication bias was assessed through funnel plot analysis and Egger's test.

## RESULTS

The sample size in the 25 studies included in the meta-analysis, 15 experimental studies, 10 quasi-experimental studies, and Sample sizes ranged from 30 to 1,500 participants. The analysis involved comparing pre- and post-test results, attitude surveys, and motivation scores. This section presents the findings, accompanied by relevant figures and tables to visualize the data.

### Pre-/Post-Test Results

**Table 1** shows that students in the experimental group who were taught using the CBT Approach showed a significant improvement in their chemistry test scores compared to the control group, with a mean gain of 16.9 points as compared to 2.9 points in the control group.

**Table 2.** Attitude towards chemistry

Attitude statement	Control group (pre-test)	Control group (post-test)	Experimental group (pre-test)	Experimental group (post-test)
Chemistry is an interesting subject	3.2	3.4	3.3	4.5
I enjoy solving chemistry problems	2.9	3.1	2.8	4.3
I am confident in my chemistry skills	2.7	2.9	2.8	4.4
I believe chemistry is important	3.5	3.6	3.4	4.6

**Table 3.** Motivation towards chemistry

Motivation metric	Control group (pre-test)	Control group (post-test)	Experimental group (pre-test)	Experimental group (post-test)
Intrinsic motivation	2.8	2.9	2.7	4.2
Self-efficacy	2.9	3.0	2.9	4.5
Mastery goal orientation	3.0	3.1	2.9	4.7

### Attitude Towards Chemistry

**Table 2** shows that students in the experimental group reported a more positive attitude toward chemistry after being taught through CBTA. The biggest gains were seen in statements related to enjoyment and confidence.

#### Effect on Attitudes

The competency-based approach also significantly influenced students' attitudes toward chemistry (mean effect size = 0.58,  $p < 0.01$ ). Students reported feeling more positive toward the subject when they were allowed to demonstrate mastery in stages and to apply their knowledge in practical settings (Block & Burns, 1976). CBTA reduces the anxiety commonly associated with chemistry learning by promoting a supportive and self-paced learning environment (Edjlali, 1990). The CBTA had a significant impact on students' intrinsic motivation and self-efficacy (**Table 3**). The experimental group showed a notable increase in motivation across all three categories, especially in mastery goal orientation.

#### Effect on Motivation

The meta-analysis revealed a significant positive impact of CBTA on student motivation toward chemistry (mean effect size = 0.65,  $p < 0.01$ ). The studies showed that students in CBTA environments demonstrated higher levels of intrinsic motivation compared to those in traditional settings. This effect was particularly pronounced in studies that emphasized hands-on, competency-driven tasks where students could see real-world applications of chemistry (Dodier, 2020).

### Moderating Variables

#### Student age

Significant moderator for attitudes ( $p < 0.01$ ) and motivation ( $p < 0.05$ ), study design: significant moderator for learning outcomes ( $p < 0.05$ ), and CBT approach duration: significant moderator for attitudes ( $p < 0.05$ ).

#### Subgroup analysis

High school students:  $g = 0.55$  (95% confidence interval [CI]: 0.30, 0.80) for attitudes, university students:  $g = 0.35$  (95% CI: 0.15, 0.55) for attitudes, experimental studies:  $g = 0.60$  (95% CI: 0.35, 0.85) for learning outcomes.

#### Meta-regression

Student age:  $\beta = -0.02$  ( $p < 0.05$ ) for attitudes and study design:  $\beta = 0.15$  ( $p < 0.05$ ) for learning outcomes.

### Moderator analyses

The positive effects on both attitudes and motivation were moderated by several factors: education level: high school students exhibited greater gains in motivation compared to undergraduates, suggesting that CBTA may be particularly beneficial at earlier stages of education and implementation fidelity: studies that applied CBTA with high fidelity (regular assessments, feedback, and alignment with learning goals) showed more substantial positive effects. Moderating variables, such as student age and study design, influence the magnitude of these effects.

## DISCUSSION

This meta-analysis provides evidence that CBT approaches positively impact students' attitudes, motivation, and learning outcomes in chemistry (Henri et al., 2017). The overall effect sizes indicate that these approaches can lead to improved attitudes, motivation, and learning outcomes, with moderate to large effects. The findings suggest that CBT approaches are effective in promoting positive attitudes toward chemistry, particularly among high school students (Potvin et al., 2012). This is consistent with previous research highlighting the importance of relevance and interest in science education (Osborne et al., 2003). The results also indicate that CBT approaches can enhance motivation toward chemistry, although the effect size is smaller compared to attitudes (Almendra, 2019). This may be due to the complex nature of motivation, which is influenced by multiple factors (Ryan & Deci, 2020). The impact of CBT approaches on learning outcomes in chemistry is also noteworthy. The results suggest that these approaches can lead to improved learning outcomes, particularly in experimental studies (Burch et al., 2019). The moderating variables, such as student age and study design, highlight the importance of considering contextual factors when implementing CBT approaches. For example, younger students may benefit more from these approaches in terms of attitudes and motivation. The findings from this meta-analysis suggest that CBTA is an effective pedagogical approach for improving students' attitudes and motivation toward chemistry. The emphasis on individual competency and real-world applications appears to engage students more deeply than traditional methods, which often focus on abstract concepts and memorization (Saavedra & Opfer, 2012). By fostering a more active and supportive learning environment, CBTA helps students gain

confidence in their abilities, reducing the anxiety often associated with chemistry.

These findings align with broader educational theories that support mastery learning and student-centered instruction as more effective ways of promoting engagement in challenging subjects. However, the success of CBTA seems to depend on its proper implementation and the level of student support provided (Voorhees, 2001).

## CONCLUSION

This meta-analysis demonstrates that the CBT approach has a positive impact on both attitudes and motivation toward chemistry. Educators aiming to improve student engagement in chemistry should consider adopting CBTA strategies that focus on individualized learning, practical applications, and regular feedback. Further research is needed to explore long-term impacts on student achievement and whether these effects are sustained across different demographic groups. The results have important implications for chemistry education, highlighting the potential of CBT approaches to enhance student learning and engagement. Teachers, educators, and policymakers can use these findings to inform evidence-based practices and promote innovative teaching methods.

### Recommendations

Based on the findings of this meta-analysis on the impact of CBT approaches on students' attitudes and motivation toward chemistry education, the following recommendations are proposed for educators, administrators, and policymakers:

Schools and educational institutions should consider incorporating CBT approaches in chemistry education. This learner-centered approach fosters greater student engagement, motivation, and self-efficacy, leading to improved academic performance and interest in chemistry. Effective implementation of competency-based learning requires that teachers be adequately trained. Ongoing professional development programs should be introduced to equip educators with the knowledge and skills needed to design and facilitate competency-based curricula. Training should focus on student-centered teaching strategies, assessment techniques, and classroom management within this framework.

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