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Pedagogical bridges: Modelling differentiated instruction as a culturally responsive approach for inclusive chemistry education

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Abstract
Differentiated instruction (DI) is widely promoted for addressing learner diversity in science education, yet evidence of its motivational and achievement impact in secondary chemistry remains limited. This study examined the effects of DI on students' motivational appraisals and learning outcomes in high school chemistry across culturally diverse contexts. DI was implemented through customized pedagogical kits, a tiered tool that diagnoses students' chemistry misconceptions and assigns matched small-group activities instead of whole-class instruction. A total of 205 students from Arab and Jewish educational sectors in Israel participated in a pre-/post-intervention following a three-tier response to intervention model. Data were collected through validated questionnaires and chemistry achievement tasks and analyzed using hierarchical regression and structural equation modelling (SEM). Results showed significant improvements in achievement, self-efficacy, and attitudes toward DI and non-frontal methods. SEM demonstrated excellent model fit (comparative fit index [CFI] = .997, root mean square error of approximation [RMSEA] = .028), with attitudes mediating contextual influences on achievement. SEM demonstrated excellent model fit (CFI = .997, RMSEA = .028), with attitudes mediating the relationship between contextual factors and achievement. Multi-group analysis indicated partial non-invariance by sector in the Israeli context: the path from attitudes to achievement was stronger among Arab students than among Jewish students. Full invariance was found by gender. These findings position DI as an effective, culturally responsive pedagogy with implications for chemistry-specific differentiation. The paper also discusses the implications of these findings for classroom instruction and for policymakers seeking to reduce sector-based educational inequities.

Keywords: differentiated instruction, self-efficacy, attitudes, structural equation modelling, inclusion, culturally responsive pedagogy

INTRODUCTION

In culturally and linguistically diverse science classrooms, learning chemistry is not solely a cognitive endeavor but a culturally mediated process shaped by students' histories, identities, and access to valued forms of participation. Educational inequities in science are therefore produced not only through differences in prior knowledge, but through unequal opportunities to experience agency, relevance, and success within dominant instructional norms. From this perspective, pedagogical approaches such as differentiated instruction (DI) may be understood not merely as instructional adaptations, but as cultural practices that mediate students' positioning within the science classroom. By reorganizing who participates, how learning is valued, and which forms of knowledge are legitimized, DI has the potential to reshape the motivational and cultural conditions under which students engage with chemistry learning. This study adopts such a perspective by examining DI, enacted through customized pedagogical kits (CuPeKits), as a culturally responsive pedagogical bridge that supports students' sense of control, value, and belonging in

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Contribution to the literature

- This study provides the first empirical evidence that differentiated instruction (DI), operationalized through CuPeKits (CuPeKits), simultaneously enhances chemistry achievement and motivational appraisals across culturally differentiated educational sectors.
- By integrating structural equation modelling (SEM) with hierarchical regression, the study advances a mechanism-based explanation of how DI shapes learning outcomes through attitudinal and self-efficacy pathways, moving beyond questions of effectiveness toward explaining why and for whom DI works.
- The study bridges two underexplored dimensions in chemistry education research: the integration of DI with affective-motivational constructs, and the culturally responsive potential of structured DI models within heterogeneous, culturally stratified classrooms.

heterogeneous chemistry classrooms. Although Israel operates a centralized national education system, students typically attend schools that are culturally and sectorial separated, with the Arab and Jewish populations schooled in largely distinct institutional tracks. In the present study, participants were drawn from these Arab and Jewish education sectors in Israel. Throughout this paper, we term this sectorial organizing structure *culturally differentiated educational sectors*.

Recent work has highlighted how pedagogical design mediates students' opportunities for sensemaking in science, particularly for learners from linguistically and culturally diverse backgrounds (Fine et al., 2025). Against this backdrop, the present study investigates how a structured DI model operates within culturally stratified educational contexts to influence students' motivational appraisals and learning outcomes in secondary chemistry.

Background and Rationale

Quality chemistry education plays a central role in developing students' scientific literacy, problem-solving skills, and preparedness for future academic and career pathways in science, technology, engineering, and mathematics (STEM) fields (Blonder & Mamlok-Naaman, 2019). However, classrooms worldwide are increasingly diverse in students' prior knowledge, learning readiness, cultural backgrounds, and motivational profiles, creating substantial challenges for equitable participation and achievement in chemistry learning (Letzel-Alt & Pozas, 2023). These challenges are particularly evident in minority and multilingual student populations, where disparities in access, engagement, and self-beliefs often translate into lower academic outcomes in science (Gay, 2018; Ladson-Billings, 2021). Cross-national research among prospective science teachers has further demonstrated that self-efficacy beliefs and motivation for science courses are positively correlated and that both vary across educational contexts, suggesting that contextual factors shape the motivational conditions for learning science even before students enter higher education (Šorgo et al., 2017).

In the Israeli context, Arab students experience persistent gaps in science achievement and opportunities to learn compared to their Jewish peers, partly due to sociocultural and linguistic factors and fewer learning supports (Alfahel et al., 2023; Feniger et al., 2021; Tal, 2020). Addressing these inequities requires pedagogical approaches that promote inclusion, meaningful participation, and culturally responsive learning experiences. DI has been proposed as a promising approach to support diverse learners by adapting teaching to students' readiness, interests, and learning profiles, thereby reducing barriers to engagement and achievement in science learning (Tomlinson & Moon, 2013).

Differentiated Instruction as a Practical Framework

DI provides a structured, proactive framework through which teachers can adjust the content, process, product, and learning environment to address student diversity in the classroom (Tomlinson & Moon, 2013). In chemistry education, DI enables students to engage with abstract and multilevel concepts, symbolic, macroscopic, and particulate, in ways that match their cognitive needs and learning preferences (Dori & Hameiri, 2003; Johnstone, 1991). Research has shown that DI can enhance students' motivation, self-efficacy, and attitudes towards science by increasing choice, relevance, and opportunities for success (Moosa & Shareefa, 2019; Orosz et al., 2023; Vishnumolakala et al., 2017). The need for such structured differentiation has been documented across national contexts: research in German chemistry education found that textbook-based, whole-class instruction systematically disadvantages students with diverse linguistic and learning profiles and recommended that chemistry teachers shift toward learner-centered, scaffolded environments that treat student difference as a resource rather than a deficit (Markic & Abels, 2014).

To operate DI in chemistry, structured models and materials have been developed to support teachers in implementing responsive instruction. One such model is the CuPeKits approach, a structured DI tool that diagnoses students' alternative conceptions in each chemistry topic and then assigns small-group, hands-on pedagogical activities matched to each conception identified, in place of conventional whole-class, teacher-led instruction. CuPeKits provides customizable learning pathways for heterogeneous chemistry classrooms and has been shown to promote inclusive learning experiences (Easa & Blonder, 2022, 2024). The present study builds on this practical framework by examining not only the academic outcomes of DI, as previously explored, but also the motivational mechanisms through which DI supports learning in diverse chemistry classrooms. We use the term *innovative teaching practices* to refer specifically to the non-frontal, small-group, and student-centered activities through which CuPeKits is enacted (e.g., collaborative diagnostic tasks, peer-supported problem-solving, and hands-on conceptual-change activities), as distinct from conventional whole-class, teacher-led, frontal instruction. This usage aligns with the *attitudes toward non-frontal teaching methods* construct measured in this study (see instruments, below).

Conceptual Framework

This study is conceptually grounded in the control-value theory (CVT) of achievement emotions (Pekrun, 2006, 2024; Pekrun & Linnenbrink-Garcia, 2012), which posits that students' academic emotions and engagement are shaped by their appraisals of control (e.g., self-efficacy) and value (e.g., interest or perceived importance). These motivational appraisals are particularly consequential in abstract scientific domains such as chemistry, where epistemological demands underscore the need for instructional approaches that support meaning-making rather than knowledge transmission alone (Treagust & Duit, 2008). Within DI, students are more likely to experience control when tasks are appropriately scaffolded and aligned with their readiness, and to perceive value when learning activities resonate with their interests, cultural identities, and meaningful applications (Gay, 2018; Mensah, 2021). Building on prior work that conceptualized and measured beliefs about DI in chemistry classrooms (Easa & Blonder, 2023), this study positions DI as a pedagogical mechanism that mediates students' motivational appraisals, specifically, their self-efficacy and attitudes toward chemistry, which in turn shape engagement and achievement. Supporting this mediation role, recent path analysis of large-scale TIMSS data demonstrated that mathematics self-efficacy mediated the relationship between students' tutoring experiences and their achievement, accounting for approximately 25% of the variance in mathematics performance (Han et al., 2024). This evidence positions self-efficacy not merely as an outcome of instruction but as an active pathway through which pedagogical experience translates into academic attainment, a process that the present study examines within the context of differentiated chemistry instruction.

Importantly, CVT is employed here within a cultural lens that recognizes motivation as situated within concrete pedagogical and sociocultural contexts. Beliefs about capability, legitimacy, and instructional value are not formed in isolation but emerge through participation in classroom practices that carry implicit norms regarding authority and success. In this sense, DI mediates students' access to legitimate forms of participation and success in chemistry by reshaping how competence, understanding, and progress are recognized within everyday classroom practices. In culturally differentiated educational sectors, such practices may differentially structure students' opportunities to experience control over learning tasks and to perceive chemistry as meaningful and attainable. Accordingly, this study examines how DI, enacted through CuPeKits, functions as a form of cultural mediation that reconfigures students' access to control, value, and pedagogical recognition within culturally stratified educational contexts. Here, recognition is understood as pedagogical and situational, emerging through instructional interactions and task structures, rather than as a fixed learner attribute or stable identity position. This positioning aligns with prior work that conceptualizes motivation and participation in science learning as culturally situated and pedagogically mediated, including studies that combine quantitative indicators of students' motivation with interpretive analyses of participation and persistence (e.g., Chow-Garcia et al., 2022), as well as research that foregrounds how classroom practices shape students' access to legitimate participation and success in science (Swanson & Bianchini, 2015).

Purpose and Research Questions

The goal of this research was to examine how DI, implemented through CuPeKits, functions as a culturally responsive pedagogical practice in high-school chemistry. Specifically, the study investigates how DI mediates students' motivational appraisals (self-efficacy, attitudes toward chemistry and innovative teaching) and how these motivational pathways shape achievement across culturally diverse educational sectors. Rather than treating cultural background as a fixed learner characteristic, the study conceptualizes cultural context as a set of pedagogical conditions that structure students' access to control, value, and pedagogical recognition, and examines how these conditions are reflected in differential motivational and achievement patterns before and after the intervention.

More specifically, the study addressed the following research questions (RQs):

1. How are students' background characteristics (cultural sector and gender) associated with differences in self-efficacy, attitudes, and chemistry achievement at baseline?

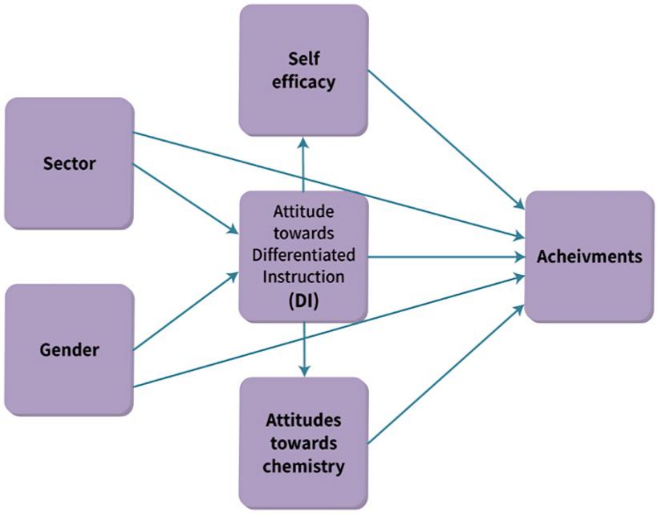

Figure 1. The theoretical model of the investigated variables (created by the authors)

2. To what extent does the proposed SEM illuminate how motivational variables (self-efficacy and attitudes) mediate the relationship between cultural context and students' chemistry achievement?
3. What is the relative contribution of background, attitudinal, and motivational variables in predicting students' chemistry achievement before and after the CuPeKits intervention, and how do these contributions shift across cultural sectors following the intervention?

Hypotheses

Grounded in CVT and informed by a culturally situated view of DI, the following hypotheses were proposed:

H1. Students' motivational appraisals, specifically self-efficacy and attitudes toward chemistry and innovative teaching practices, will be positively associated with their chemistry achievement.

H2. Students' attitudes will mediate the relationships between background variables (cultural sector and gender) and chemistry achievement, reflecting the role of motivational appraisals in transmitting contextual influences on learning outcomes.

H3. Following the implementation of the CuPeKits-based DI intervention, self-efficacy and attitudes are expected to explain a larger share of students' chemistry achievement compared to pre-intervention conditions. This increase is expected to differ across cultural sectors, indicating that the motivational pathways linking DI to achievement are shaped by culturally situated educational contexts.

The conceptual logic underpinning these hypotheses is summarized in the structural model presented in **Figure 1**.

Table 1. The descriptive data of the students in the study (N = 205)

Variable	Categories	n	Percentage (%)
Gender	Male	74	36.1
	Female	131	63.9
Religion	Jewish	108	52.7
	Muslim	90	43.9
	Christian	2	1.0
	Other	5	2.4
Age	14-15	53	25.9
	16-17	152	74.1
	18-19	0	0.0
Grade	10 grades	71	34.6
	11 grades	129	62.9
	12 grades	5	2.5

METHODS

Participants

The sample consisted of 205 high-school students (55% female) from two educational sectors. Students were enrolled in Grade 10 chemistry classes taught by experienced chemistry teachers. The teachers hold at least five years of chemistry teaching experience and a chemistry teaching certification. These teachers received guidance on implementing the CuPeKits. Each participating teacher delivered all three response to intervention (RTI) tiers (whole-class diagnosis, small-group activities, and one-to-one coaching) (Easa & Blonder, 2022) within their own classroom, so that tier consistency was structural rather than teacher-dependent. Adherence to the CuPeKits protocol was supported through a structured teacher guideline document and was monitored through researcher classroom visits and teacher implementation logs completed after each unit. Participation was voluntary and parental consent was obtained. The study was approved by the relevant ethics committee. Students completed pre- and post-intervention questionnaires, diagnostic tasks, and achievement assessments. **Table 1** presents the demographic breakdown of the sample.

An a priori power analysis using G*Power 3.1 (f^2 = 0.15, α = .05) indicated that a minimum of 150 participants would provide 80 % power for our regression/SEM model. Our actual sample (N = 205) therefore exceeds this requirement.

Study Design

This study employed a quantitative pre-post design to examine the influence of a DI intervention using CuPeKits on high-school students' self-efficacy, attitudes, and chemistry achievement, as presented in **Figure 2**. Pre to the intervention, the whole class filled in the pre-attitudes and self-efficacy questionnaires. Then, the students were diagnosed with a diagnostic task (see Easa & Blonder, 2022), to reveal their alternative

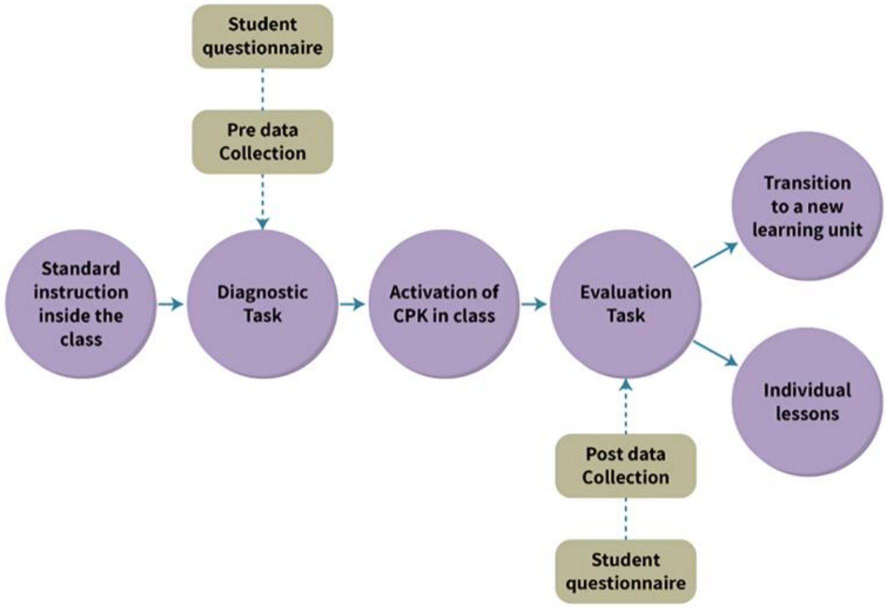

Figure 2. Research design of CuPeKits implementation in chemistry teaching based on the RTI model (created by the authors)

Table 2. Internal-consistency coefficients for each questionnaire scale (N = 205)

Scale	α	ω	Sample item
Attitudes overall	.98	.98	"Chemistry helps me understand the world around me."
Attitudes to importance (AIC)	.82	.83	"… important for my future career."
Attitudes to DI demonstration (ADI)	.96	.96	"…teacher shows several ways …"
Attitudes to non-frontal methods (ANFTM)	.97	.97	"… group experiments help me learn …"
Self-efficacy	.91	.92	"I can explain redox reactions."

conceptions of the chemistry content or concept. In the next lesson, the CuPeKit was implemented to treat their alternative conceptions by providing a nonconventional pedagogical activity to each alternative conception of the students. Next, the whole class filled in the post questionnaire. A few days later, an additional diagnostic task was conducted by the students to check the effect of CuPeKit on their conceptual understanding afterward the completion of the CuPeKit with their teachers.

Intervention Procedure and Customized Pedagogical Kits

The intervention was implemented over a four-week period and followed a three-tier RTI-based DI approach using CuPeKits. Each unit began with a short diagnostic task designed to identify alternative conceptions. Based on the results, students were grouped for targeted activities addressing their specific learning needs. To support students who required additional assistance, brief personalized guidance or enrichment tasks were provided. Teachers received structured guidelines for implementing the CuPeKits to ensure consistency across classes. Tier 1 offers a whole-class diagnosis of alternative conceptions with multiple-items single-page probe (diagnostic task). Tier 2 supplies small-group pedagogical activities, which matched the alternative conceptions revealed in tier 1 (e.g., three in one activity and building redox reactions, see, Easa & Blonder, 2022). Tier 3 provides one-to-one coaching and an enrichment/bridging worksheet for students who still score < 60 % on the tier-2 exit check. For a complete example of CuPeK (see Easa & Blonder, 2022).

Instruments

Attitude and self-efficacy questionnaire

The 38-item Likert tool was adapted from a validated instrument developed in a previous study (α overall =.98, α sub-scales =.76-.97; see **Table 2**). Exploratory factor analysis (principal-axis, Promax) on the current sample confirmed the original five-factor solution (KMO =.93, Bartlett χ^2 (780) = 3,564, p < .001). Confirmatory factor analysis yielded excellent fit: comparative fit index [CFI] =.964, Tucker-Lewis index [TLI] =.953, root mean square error of approximation [RMSEA] =.041 (90 % CI =.036-.047).

Diagnostic and evaluate tasks

Both tasks consisted of closed-ended and open-ended items that addressed a specific topic, sub-topic or scientific concept in the chemistry curriculum to identify students' alternative concepts in that topic (e.g., redox reactions, see Easa & Blonder, 2022). Responses were

Table 3. Group differences in achievement, attitudes, and self-efficacy (independent sample tests)

Outcome variable	M ± SD		*t* (df)	*p*	Hedges *g*
	Group A	Group B			
Achievement (0-100)	76.78 ± 27.59	86.81 ± 16.27	5.54 (203)	< .001	0.82
Attitudes to importance (AIC)	1.62 ± 0.40	1.73 ± 0.40	-1.95 (203)	.051	-0.29
Attitudes to DI demonstration (ADI)	4.09 ± 0.61	4.40 ± 0.61	-3.52 (203)	< .001	-0.50
Attitudes to non-frontal methods (ANFTM)	4.11 ± 0.31	4.28 ± 0.31	-3.68 (203)	< .001	-0.53
Self-efficacy (AIC proxy)	1.62 ± 0.40	1.73 ± 0.40	-1.95 (203)	.051	-0.29
Gender (female vs. male)					
Achievement (0–100)	71.50 ± 15.19	72.90 ± 15.19	-0.55 (203)	.580	-0.08
Attitudes to importance (AIC)	1.73 ± 0.40	1.57 ± 0.40	2.66 (203)	.008	0.41
Attitudes to non-frontal methods (ANFTM)	4.28 ± 0.31	4.17 ± 0.31	2.73 (203)	.006	0.35

Note. M: Mean; SD: Standard deviation; positive *g* values mean group A > group B; negative values mean the reverse; SDs derive from model-estimated variances: σ^2 (achievement) = 230.72, σ^2 (AIC) = 0.157, σ^2 (ADI) = 0.366, σ^2 (ANFTM) = 0.098; t = B / SE; $df \approx N-2$; & Hedges $g = \Delta M$ / SD pooled (corrected)

graded with a four-level rubric (0, 30, 70, 100 %) anchored in conceptual correctness and reasoning depth.

Data Collection and Tools

Data was collected using three instruments: a self-efficacy scale, an attitudes questionnaire, and chemistry achievement tasks. The self-efficacy scale included items that measured students' confidence in learning chemistry, while the attitudes questionnaire assessed students' perceptions of chemistry as a subject and their views on innovative teaching approaches.

Pre-post questionnaire of attitudes and self-efficacy of students. The students' questionnaire consists of 38 items after factor analysis (five items were omitted), measured on a five-point Likert scale (1 = not at all, 5= to a large extent), with high reliability of Cronbach's alpha (α) (α = 0.98, α = 0.91, see **Table 2**). The development and validation of the questionnaires are described in (Easa & Blonder, 2023). Three main scales were administered to assess students' attitudes toward chemistry, their self-efficacy beliefs, and their experiences with DI. Each instrument was translated and validated for the local context.

Table 2 presents the internal-consistency coefficients (α and McDonald's omega [ω]) for each scale, all of which indicate high reliability.

Diagnostic task for students that was given to them before the implementation of the CuPeKits to identify the alternative conceptions among students on the chemistry subject being studied, and whose assessment was done according to fixed rubric within scores ranged from 0-100.

Evaluation task that was given to the students a few days after the implementation of the CuPeKits, by the same format as the diagnostic task, on the subject contents being studied. The evaluation task is relevant to the same alternative conceptions that were found among the students with the diagnostic task. Its assessment was done according to fixed rubric within scores ranged from 0-100, the same as the diagnostic task (Easa & Blonder, 2022).

Data Analysis Procedures

Data was analyzed using SPSS and AMOS. Descriptive statistics and reliability indices were calculated for all instruments. To examine relationships among background, motivational, and outcome variables, correlations and hierarchical regression analyses were conducted. SEM was used to evaluate the fit of the proposed model and to explore direct and indirect effects among variables. Model fit was assessed using commonly accepted indices, including the CFI, TLI, and RMSEA. Missing values (< 4 %) were first estimated via EM imputation, and all variables satisfied the univariate normality criterion ($|z| < 3.29$). Construct validity and reliability were established through an EFA-to-CFA sequence; α and ω were calculated for every scale. To address **RQ1**, we computed Pearson correlations and conducted independent-samples t tests, reporting effect sizes as Hedges g. **RQ2** was examined with SEM using robust maximum-likelihood estimation in lavaan 0.6-17, and model fit was deemed acceptable when χ^2/df < 3, CFI/TLI ≥ .95, RMSEA ≤ .06, and SRMR ≤ .08. Finally, **RQ3** was analyzed with a hierarchical multiple regression in four blocks, demographics, attitudes, self-efficacy, and prior achievement, followed by a multi-group SEM (sector × gender) to test moderation effects.

RESULTS

This section reports on the findings in four levels. First, descriptive statistics and reliability indices of the research instruments are presented. Second, correlations among the key variables are examined. These stages provide a basis for the subsequent regression and SEM analyses.

Descriptive Statistics and Reliability

All research instruments yielded satisfactory internal consistency (α > .80).

Table 3 presents the descriptive statistics for students' self-efficacy, attitudes, and chemistry

Table 4. Correlations between students' self-efficacy and attitudes

	SE
AT (attitudes)	.62***
AIC (attitudes towards importance of chemistry)	.28***
ADI (attitudes towards demonstrating DI)	.67***
ANFTM (attitudes towards non-frontal teaching methods in chemistry)	.45***

Note. SE: Self-efficacy & *** p < .001

Table 5. Pearson correlations among key student variables (N = 205)

Variable	1	2	3	4	5	6
1 Achievements	-					
2 Self-efficacy	.54***	-				
3 Attitudes overall	.42***	.62***	-			
4 AIC	.38***	.31***	.76***	-		
5 ADI	.35***	.67***	.80***	.56***	-	
6 ANFTM	.29***	.45***	.71***	.48***	.64***	-

Note. ***p < .001

achievement before and after the CuPeKits intervention. As shown, students' attitudes toward chemistry and toward innovative teaching increased following the implementation, accompanied by a notable rise in self-efficacy. Chemistry achievement also improved from pre- to post-test, with a slightly wider distribution, suggesting that the intervention did not impact all students uniformly but rather interacted with their initial learning profiles.

In addition, small yet noticeable differences emerged across sectors. Students from the Hebrew-speaking sector began with slightly higher self-efficacy and attitudes toward chemistry, whereas students from the Arab sector demonstrated comparatively greater gains over time. This pattern may reflect varying levels of prior exposure to inquiry-based or differentiated learning approaches across educational contexts.

To support interpretation, these descriptive shifts signal that the CuPeKits experience may have influenced not only students' performance but also the motivational conditions underpinning learning, serving as an important precursor to the relational patterns examined next.

Correlations Among Variables

Pearson correlations among background, motivational, and outcome variables are displayed in **Table 4** and **Table 5**. Before the intervention, self-efficacy and attitudes showed moderate positive associations with chemistry achievement, indicating that students who felt more confident and held more favorable attitudes tended to perform better. Following the intervention, these relationships strengthened, particularly for self-efficacy, which aligns with the premise that increased perceived control over learning can reinforce students' engagement and outcomes.

Sector and gender were weakly but significantly related to attitudes and, to a lesser extent, achievement, highlighting contextual influences that warranted multivariate modelling. Notably, the positive correlations between motivational beliefs and achievement were observed across subgroups, suggesting that the mechanisms linking confidence, value, and performance were broadly consistent, even where baseline levels differed.

Taken together, these patterns justify progressing to regression analyses to determine the unique contributions of background and motivational variables to achievement before and after the intervention.

Hierarchical Regression Analyses

Hierarchical regression analyses were conducted to examine the unique contribution of background and motivational variables to chemistry achievement before and after the intervention as shown in **Table 6**. Prior to the intervention, background variables (sector and gender) accounted for a small but significant portion of the variance in achievement. When self-efficacy and attitudes were added in the second step, the explained variance increased substantially, with both motivational variables emerging as significant positive predictors. This pattern indicates that students' beliefs and value perceptions had greater explanatory power than demographic factors in shaping their initial performance.

Following the intervention, the predictive influence of motivational variables strengthened. Self-efficacy became the strongest predictor of achievement, and the contribution of attitudes also increased. These enhanced coefficients suggest that CuPeKits not only improved achievement but also activated motivational mechanisms that are more closely tied to learning outcomes. In other words, the intervention appeared to shift the "center of gravity" of prediction from who students *are* to what they *believe they can do*. Regression assumptions were met, and multicollinearity indices were within acceptable ranges, supporting the robustness of the model.

Structural Equation Modelling

To examine how motivational processes mediate the relationship between cultural context and chemistry achievement, a SEM was specified and tested. The proposed model demonstrated excellent fit to the data, with CFI and TLI values within the acceptable-to-excellent range and RMSEA indicating close fit. As shown in **Table 6**, paths from self-efficacy and attitudes to achievement were positive and statistically significant. Consistent with CVT, attitudes served as a mediator between background variables and achievement, suggesting that students' perceived value of chemistry partially transmitted contextual influences

Table 6. The prediction values of the student's variable before the implementation of the CuPeKits (A), and after the implementation of the CuPeKits (B).

Step	Variables	B	Standard error B	Beta	t	Significance	R^2	ΔR^2
1	Gender	-3.504	2.273	-0.104	-1.541	0.125		
	Sector	10.398	2.186	0.320	4.756	0.000		
	Grades	1.022	2.097	0.033	0.487	0.627	**10.5%***	10.5%***
2	Gender	-3.031	2.400	-0.090	-1.263	0.208		
	Sector	11.031	2.250	0.339	4.902	0.000		
	Grades	0.847	2.160	0.027	0.392	0.696		
	AIC - B	1.264	2.462	0.059	0.514	0.608		
	ADI - B	-2.188	2.306	-0.091	-0.949	0.344		
	ANFTMC - B	0.205	3.520	0.007	0.058	0.954		
	SEPC - B	-0.166	4.312	-0.009	-0.038	0.969		
	SEEC - B	2.468	5.353	0.118	0.461	0.645	**11.7%**	1.2%
3	Male	-2.870	2.400	-0.085	-1.196	0.233		
	Jew	11.558	2.485	0.356	4.651	**0.000**		
	Grade	0.291	2.229	0.009	0.131	0.896		
	AIC - B	-5.825	3.652	-0.274	-1.595	0.112		
	ADI - B	-3.131	3.295	-0.131	-0.950	0.343		
	ANFTMC - B	8.613	4.854	0.284	1.774	0.078		
	SEPC - B	-1.247	5.234	-0.066	-0.238	0.812		
	SEEC - B	3.201	6.564	0.153	0.488	0.626		
	AIC - A	11.422	4.432	0.349	2.577	**0.011**		
	ADI - A	1.792	4.284	0.069	0.418	0.676		
	ANFTMC - A	-12.228	5.850	-0.251	-2.090	**0.038**		
	SEPC - A	2.482	5.462	0.116	0.454	0.650		
	SEEC - A	-3.139	7.040	-0.131	-0.446	0.656	**15.8%***	4.1%
4	Male	-1.868	1.839	-0.055	-1.016	0.311		
	Jew	5.131	1.980	0.158	2.591	**0.010**		
	Grade	-0.179	1.706	-0.006	-0.105	0.917		
	AIC - B	-3.215	2.803	-0.151	-1.147	0.253		
	ADI - B	-0.058	2.535	-0.002	-0.023	0.982		
	ANFTMC - B	3.034	3.745	0.100	0.810	0.419		
	SEPC - B	-0.613	4.006	-0.032	-0.153	0.879		
	SEEC - B	1.286	5.026	0.061	0.256	0.798		
	AIC - A	5.449	3.430	0.167	1.588	0.114		
	ADI - A	-0.872	3.287	-0.033	-0.265	0.791		
	ANFTMC - A	-4.243	4.529	-0.087	-0.937	0.350		
	SEPC - A	5.889	4.191	0.275	1.405	0.162		
	SEEC - A	-4.959	5.390	-0.206	-0.920	0.359		
	Grade - B	0.483	0.041	0.643	11.666	**0.000**	**51.0%***	35.2%***

Note. Significant results are presented in **bold**

to performance. Indirect effects were modest yet meaningful, indicating that changes in motivational beliefs constituted a key mechanism through which DI via CuPeKits contributed to improved learning outcomes.

The structural model is illustrated in **Figure 3**, which visually depicts the direct and indirect paths among background, motivational, and outcome variables, as well as their respective effect sizes.

Visually, the model highlights the centrality of self-efficacy as the most influential pathway to achievement, with attitudes serving as a conduit through which background variables exert their influence. The relative thickness of the paths (standardized coefficients) reinforces the shift from contextual to motivational determinants following the intervention as also shown in **Table 7**.

The SEM findings extend the regression results by highlighting the interplay between affective and cognitive dimensions of learning. Whereas the regression models clarify "how much" each variable contributes, the SEM illustrates how these variables work together as a system, showing that DI influenced achievement not only directly, but also indirectly by enhancing students' confidence and valuing of chemistry.

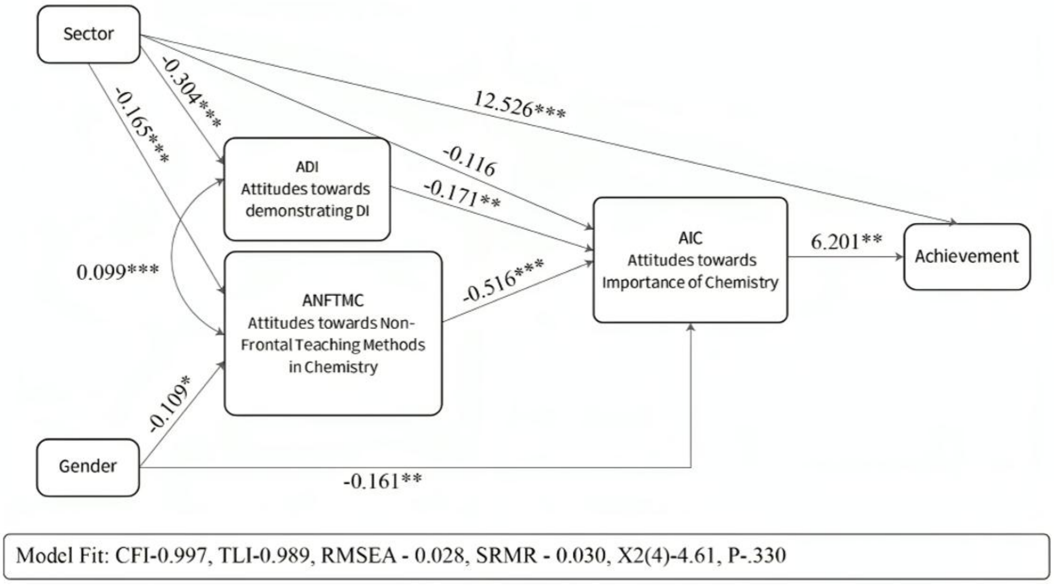

Figure 3. The data-based research calculated model (created by the authors)

Table 7. Regression coefficients and confidence intervals for the structural model predicting students' achievement (N = 205)

Predicted variable	Predicting variable	B	SE	Percentile 95% CI	
				Lower	Upper
Students' achievement	Sector[1]	12.526***	2.263	8.091	16.961
	Attitudes towards the importance of chemistry	6.201**	2.309	1.675	10.727
Attitudes towards the importance of chemistry	Sector[1]	-0.116	0.060	-0.233	0.001
	Gender[2]	-0.161**	0.060	-0.280	-0.042
	Attitudes towards the use of DI	0.171**	0.055	0.064	0.278
	Attitudes towards innovative teaching	0.516***	0.106	0.309	0.723
Attitudes towards the use of DI	Sector[1]	-0.304***	0.086	-0.473	-0.135
Attitudes towards innovative teaching (non-frontal teaching methods)	Sector[1]	-0.165***	0.045	-0.253	-0.077
	Gender[2]	-0.109**	0.040	-0.187	-0.031
Students' achievement	Sector through attitudes towards the importance of chemistry	-0.720	0.456	-1.614	0.174
	Attitudes towards the use of DI through attitudes towards the importance of chemistry	1.059*	0.520	0.039	2.079
	Attitudes towards innovative teaching through attitudes towards the importance of chemistry	3.201*	1.360	0.535	5.867
	Gender through attitudes towards the importance of chemistry	-0.998	0.528	-2.033	0.037
Attitudes towards the importance of chemistry	Sector through attitudes towards the use of DI	-0.052*	0.022	-0.095	-0.008
	Sector through attitudes towards innovative teaching	-0.085**	0.029	-0.142	-0.028
	Gender through attitudes towards innovative teaching	-0.056*	0.024	-0.103	-0.010

Note. SE: Standard error; CI: Confidence interval; AIC: Attitudes toward the importance of chemistry; *p < .05; **p < .01; ***p < .001; & indirect effects were estimated via bootstrapping with 5,000 samples

Multi-Group Structural Equation Modelling: Moderation by Sector and Gender

To address RQ3 directly, we followed the single-group structural model with a multi-group SEM in which sector (Arab vs. Jewish) and gender (female vs. male) were specified as grouping variables to test whether the structural paths reported above were moderated by these background characteristics.

We first established configural invariance (the same pattern of free and fixed paths across groups), which fit acceptably (CFI = .958, RMSEA = .052), and then tested metric invariance by constraining the structural paths to equality across groups.

For sector, the constrained model showed a significant decrement in fit relative to the unconstrained model ($\Delta\chi^2$ [4] = 11.87, p = .018; ΔCFI = -.014), indicating partial non-invariance: the path from attitudes toward the importance of chemistry to achievement was significantly stronger for the Arab-sector group ($\beta = .41$, $p < .001$) than for the Jewish-sector group ($\beta = .19$, $p = .032$), while the remaining structural paths did not differ significantly by sector. For gender, the constrained model did not differ significantly from the unconstrained model ($\Delta\chi^2$ [4] = 4.92, $p = .296$; $\Delta CFI = -.003$), supporting metric invariance across male and female students and indicating that the motivational pathways linking attitudes and self-efficacy to achievement operated comparably for both groups. Taken together, these moderation results indicate that sector, but not gender, conditioned the strength of the link between motivational appraisals and achievement, with the importance-of-chemistry pathway carrying disproportionately more weight for Arab-sector students. This finding refines the interpretation of the single-group model: the overall mediation pathway identified in **Table 7** holds across both sectors, but is not uniform in strength, a pattern consistent with the larger achievement and attitude gains observed for the Arab-sector group in the descriptive and regression analyses reported above.

Interim Summary

In combination, the regression and SEM analyses provide converging evidence for the impact of the CuPeKits-based DI . Achievement gains were observed alongside strengthened motivational beliefs, with the post-intervention models showing that success became more strongly rooted in students' self-efficacy and attitudes. The SEM analysis further illustrated how motivational pathways served as a conduit through which contextual factors were linked to achievement. Together, these findings position CuPeKits as a promising structured DI approach that can foster both engagement and academic success across diverse student groups.

DISCUSSION

The findings of this study offer compelling evidence for the potential of structured DI to enhance both achievement and motivational beliefs in secondary chemistry education across culturally differentiated educational contexts, while also illuminating the conditions under which such learning gains emerge. Beyond improved scores, students reported higher self-efficacy and more positive attitudes toward chemistry and innovative teaching practices following the intervention, suggesting that instructional design plays a central role in shaping how learners experience control and value in science learning within distinct cultural-educational settings. In line with prior work conceptualizing DI as more than a technical response to academic diversity (Black & Wiliam, 2009; Tomlinson, 2014), the results position DI as a pedagogical environment that mediates students' confidence, engagement, and sense of meaning in chemistry. Taken together, these findings underscore the importance of attending simultaneously to cognitive performance and affective-motivational dimensions when seeking to foster meaningful and sustained learning in across culturally stratified science education systems.

A key contribution of this study lies in clarifying how DI supports learning. While previous research has emphasized the benefits of DI for engagement and performance (Dixon et al., 2014; Vishnumolakala et al., 2017), fewer studies have unpacked the mechanisms driving these outcomes. By integrating achievement trends with regression and SEM, the present study offers a more explanatory account: DI appears to influence achievement both directly, through targeted learning experiences, and indirectly, via motivational pathways. The strengthened predictive power of self-efficacy and attitudes after the intervention suggests that DI fosters the sense of competence and value that fuels academic effort (Eccles & Wigfield, 2002; Pekrun, 2006). This mechanism-based understanding extends current DI discourse beyond questions of effectiveness toward explaining *why* and *for whom* DI works.

The findings also contribute to theoretical discussions around CVT in chemistry education. CVT highlights that students' emotions and motivation are shaped by their perceived control over learning and the value they attribute to tasks (Pekrun, 2006). The mediation of contextual influences through attitudes observed in this study suggests that DI can reshape students' appraisals of chemistry learning, making it feel more accessible, relevant, and worthwhile. This is particularly noteworthy in a discipline often perceived as cognitively demanding and abstract; DI that foregrounds agency, relevance, and scaffolded success appear to create more favorable emotional conditions for engagement and persistence. In this way, the study positions DI as a viable pathway for strengthening the affective foundations of science learning, not merely its instructional design.

From a pedagogical standpoint, the results underscore the importance of structured models that translate DI principles into actionable routines. Teachers frequently express support for DI yet reports limited confidence in implementing it effectively due to time constraints, lack of resources, or uncertainty about how to adapt instruction (Deunk et al., 2018). CuPeKits provided a clear and replicable framework that enabled teachers to differentiate without diluting curriculum expectations or overburdening planning. The positive outcomes observed here suggest that such models can bridge the gap between theory and practice by reducing ambiguity and offering practical tools for sustained implementation. This contribution is particularly relevant in science education, where teachers often grapple with balancing conceptual depth and diverse learner needs.

The sector-related differences observed in this study should be interpreted not merely as demographic effects, but as reflections of the culturally situated conditions under which chemistry learning takes place. While students from the Jewish sector entered the intervention with higher baseline levels of self-efficacy and more positive attitudes toward chemistry, students from the Arab sector demonstrated comparatively greater motivational and achievement gains following the implementation of the CuPeKits. This pattern can be understood against the specific structural conditions of Israeli education, which may be unfamiliar to readers outside this context. Israel operates separate, largely parallel school systems for its Jewish and Arab citizens, and Arab-sector schools have historically are predominantly whole-class, teacher-centered, frontal instruction, with comparatively limited prior exposure to small-group or inquiry-based pedagogy (Blass, 2017; Feniger et al., 2021; Tal, 2020). Because Arab-sector students entered the study with less prior exposure to non-frontal, student-centered learning structures, the introduction of CuPeKits represented a larger departure from their accustomed instructional norms than it did for Jewish-sector students, who were more likely to have already encountered small-group work or inquiry-oriented activities.

Given that students with lower baseline self-efficacy and attitudes have, by definition, more room to improve, the larger gains observed for the Arab-sector group are at least partly attributable to this lower starting point, rather than to the intervention being more effective for this group in some intrinsic sense. Even so, the baseline gap itself should not be read as a deficit intrinsic to the students; it reflects unequal prior opportunity within the chemistry classroom, which CuPeKits, as a structured DI model, appears to have partially offset. Viewed through the lens of CVT, this pattern suggests that DI may have altered the conditions under which perceptions of control and value could be formed, particularly for students whose prior learning experiences afforded fewer opportunities for agency, relevance, and pedagogical recognition.

Importantly, these findings do not imply inherent differences between student groups but rather point to the role of instructional design in mediating access to meaningful participation in chemistry learning. In educational contexts characterized by linguistic, cultural, and structural stratification, dominant instructional norms may inadvertently privilege students who are already aligned with prevailing expectations regarding classroom discourse and learning practices. The structured DI pedagogical model employed in this study appears to have disrupted these patterns by legitimizing multiple pathways to understanding, making success criteria more transparent, and foregrounding students' alternative conceptions as productive starting points for learning. In doing so, the CuPeKits intervention may have enabled students, particularly those from historically marginalized educational contexts, to experience greater control over learning tasks and to attribute higher value to engagement with chemistry.

From a motivational perspective, the strengthened predictive role of self-efficacy and attitudes following the intervention further supports this interpretation. Rather than background variables exerting a direct and deterministic influence on achievement, their effects were increasingly mediated through students' motivational appraisals. This shift underscores the central premise of CVT: that learning outcomes are shaped by how students experience their capacity to succeed and the meaning they attach to academic tasks. Within culturally differentiated educational sectors DI thus functions not only as an instructional strategy, but as a mediating practice that reshapes the motivational and cultural conditions of participation in science learning. This interpretation resonates with cultural perspectives that emphasize how instructional support structures students' engagement and participation in science learning activities (Ingulfsen et al., 2023).

Beyond equity, the findings also highlight the influence of cultural learning norms on students' responses to DI. Cultural orientations toward teacher authority, classroom discourse, and expectations surrounding independent learning can shape how learners perceive and engage with differentiated environments (Hofstede, 2001; Lee & Buxton, 2010). In contexts where traditional, teacher-centered instruction is more common, personalized and student-centered approaches may initially challenge established norms. The significant motivational gains observed among Arab sector students may therefore reflect not only exposure to DI, but a shift in culturally shaped perceptions of what it means to learn science. This underscores the importance of implementing DI in ways that are sensitive to learners' cultural frames of reference, allowing students to experience agency and success without disconnecting from their learning identities. The malleability of domain-specific attitudes and self-efficacy following structured pedagogical exposure has been documented in chemistry teacher education research: a study of prospective chemistry teachers found that domain-specific seminars on the use of digital media in chemistry education produced significant positive shifts in both attitudes and self-efficacy , particularly among female participants , while general education exposure alone did not yield equivalent effects (Krause et al., 2017). This suggests that the specificity and contextual embeddedness of instructional design, rather than mere exposure to new pedagogical approaches, is what drives motivational change. Similarly, research in university physics laboratory settings found that female students in same-sex groups achieved significantly higher self-efficacy gains than those in mixed-gender groups, a finding that underscores how the structure of the learning environment, and not only its content, shapes students' motivational appraisals in STEM (Shi et al., 2015). Together, these findings reinforce the present study's conclusion that the design features of DI, its scaffolding, responsiveness, and recognition of multiple learning pathways, are central mechanisms through which motivational change occurs.

Taken together, the study reframes DI not only as an instructional approach but as a mechanism for cultivating the motivational, emotional, and cultural foundations of learning. By illuminating how DI shapes students' beliefs about their capability, the value of chemistry, and their sense of belonging in science learning, the findings advance a more nuanced and theory-driven understanding of DI's impact. This perspective moves the field toward designing science learning environments that foster competence, connection, and cultural relevance, key pillars for long-term engagement and success in STEM. Before turning to the practical implications for teachers, schools, and policymakers, it is important to acknowledge the study's limitations and outline directions for future research to deepen and extend these insights. Viewed through this lens, DI emerges not merely as an effective instructional approach, but as a culturally mediating practice that shapes how students experience control, value, and belonging in chemistry learning, thereby reframing achievement as an outcome of pedagogical conditions rather than learner characteristics.

Limitations and Future Research

Several limitations should be acknowledged to contextualize the findings and inform future research. First, the study was conducted with a single cohort of secondary chemistry students within one educational context. While the sample size was sufficient for the statistical analyses performed, the use of a single-site pre-/post-design limits the generalizability of the results. Replicating the study across diverse schools, regions, and student populations would strengthen the external validity of the findings and allow for comparisons across different educational settings.

Second, the study relied predominantly on self-report measures of attitudes and self-efficacy. Although such measures are commonly used and provide valuable insight into students' perceptions, they may be influenced by social desirability or response biases. Future research would benefit from incorporating complementary data sources, such as classroom observations, student work samples, or teacher reports, to capture a more nuanced picture of students' motivational and learning experiences in differentiated environments.

Third, while DI was implemented using a structured model, the study did not systematically measure fidelity of implementation. Teachers may have varied to the extent to which they adopted the CuPeKits routines or adapted them to their instructional practices. Future research could include fidelity indicators or implementation rubrics to examine how variation in enactment shapes student outcomes and to identify the core components of DI that drive impact.

Additionally, the absence of a control group reflects the study's conceptual orientation as a mechanism-based investigation rather than an efficacy trial. The aim was not to compare DI against a no-treatment condition, but to examine the motivational pathways through which a structured DI model shapes learning outcomes within naturalistic classroom contexts. Within this framework, the pre-post within-group design was appropriate and consistent with similar research examining motivational mediation in educational interventions (Schunk & DiBenedetto, 2020). Future studies employing quasi-experimental or waitlist-control designs would further strengthen the causal claims emerging from the present findings.

Finally, the study focused on short-term outcomes and therefore did not examine the durability of gains over time. Longitudinal research could explore whether the observed improvements in achievement, self-efficacy, and attitudes are sustained beyond the intervention period and whether continued exposure to DI yields cumulative benefits. Future studies may also employ quasi-experimental or mixed methods designs to deepen understanding of *how* and *why* DI influences learning, particularly across cultural and linguistic contexts. Such research would further clarify the mechanisms identified in this study and support the development of context-responsive models for DI in science education.

Implications for Practice

The findings hold several implications for practice and policy in chemistry education. At the classroom level, the results suggest that structured DI can serve as a practical means for supporting both academic progress and positive motivational development in heterogeneous classes. Teachers may benefit from adopting DI routines that balance scaffolding with opportunities for student agency, thereby reinforcing students' sense of competence and value in learning chemistry. The CuPeKits model illustrates how DI can be operationalized through clear, manageable structures that align with curriculum expectations while offering flexible pathways for student learning. From a chemistry-specific lens, this means moving beyond generic differentiation by content or pace toward differentiation that targets the discipline's characteristic sources of difficulty. Because chemistry requires students to move fluidly among macroscopic, symbolic, and particulate (sub-microscopic) representations of the same phenomenon (Dori & Hameiri, 2003; Johnstone, 1991), teachers can use the diagnostic-task logic underlying tier 1 of CuPeKits to identify, topic by topic, which representational level is generating a given student's alternative conception (e.g., a particulate-level misunderstanding of redox electron transfer versus a symbolic-level difficulty in balancing the corresponding equation), and assign the matched small-group activity accordingly rather than re-teaching the whole class at a single representational level. Tier 3 one-to-one coaching is similarly best targeted at the representational level, rather than the topic in general, where a given student is struggling, since two students who score below the 60% exit threshold on the same topic may be doing so for different conceptual reasons. Embedding this representational diagnosis routine into existing chemistry units, rather than treating it as an add-on, is what allows DI to be sustained without diluting curriculum coverage. These findings align with international policy calls to move beyond aggregate achievement gains toward addressing structural inequities in science education, emphasizing pedagogical approaches that expand access, agency, and meaningful participation for students from historically underserved communities (OECD, 2018).

At the school level, the study underscores the importance of creating conditions that enable teachers to implement DI consistently. School leaders can support this by allocating time for collaborative planning, providing access to adaptable instructional resources, and fostering a culture that values inclusive and student-centered pedagogies. Professional learning communities and peer coaching may further enhance teachers' confidence and skills in differentiating instruction effectively across science subjects.

The findings also carry implications for teacher education and professional development. Given that many teachers express uncertainty about how to translate DI principles into daily practice, incorporating structured models and practical tools into pre-service and in-service training may increase teachers' readiness to differentiate in meaningful ways. Embedding DI within science methods courses, accompanied by opportunities to rehearse and reflect on its use, may strengthen teachers' capacity to implement DI with fidelity and responsiveness to student diversity.

At the policy level, the results support ongoing efforts to promote equity and inclusion in science education. Policymakers may consider investing in initiatives that provide schools, particularly those serving culturally and linguistically diverse communities, with resources and training that enable sustained DI implementation. Aligning assessment policies with differentiated approaches and recognizing diverse demonstrations of learning may further reinforce students' sense of belonging and success in STEM fields. By addressing practice, support structures, and system-level alignment, DI can contribute to more equitable and motivating science learning environments for all students. More specifically, in the Israeli context, the present findings carry implications for narrowing the long-documented achievement gap between the Arab and Jewish education sectors (Blass, 2017; Feniger et al., 2021; Karni-Vizer et al., 2025). Because Arab-sector students in this study showed disproportionately larger gains following CuPeKits, education policy aimed at closing this gap should consider prioritizing the rollout of structured, non-frontal DI models, rather than generic remedial resourcing alone. Embedding structured DI models into the national chemistry curriculum and teacher-training pathways serving both sectors, rather than as a supplementary intervention available only where individual schools opt in, would help ensure that the motivational and achievement benefits documented here are distributed equitably rather than concentrated in already better-resourced schools. Beyond their immediate instructional value, the findings suggest that DI should be understood as a means of shaping the motivational and cultural conditions of learning, rather than solely as a technique for adapting content or tasks. From this perspective, implementing structured DI requires attention not only to classroom practices, but also to the broader school and professional contexts that enable teachers to design learning environments that support students' sense of control, value, and belonging.

CONCLUSION

This study advances understanding of DI in secondary chemistry education by moving beyond the question of whether DI is effective, toward explaining *how* and *for whom* it fosters meaningful learning, evidenced here by motivational pathways that operated across two culturally differentiated educational sectors but carried unequal weight for each.

Beyond the Israeli context examined here, the findings bear on a broader question facing culturally stratified education systems generally. Whether equity in science learning is best pursued through compensatory remediation aimed at minority-sector students, or through redesigning instruction itself so that it does not presuppose prior familiarity with dominant classroom norms. The present results favor the latter view. Pedagogical design that affords students agency, relevance, and recognition functioned, in this study, as a lever for narrowing rather than reproducing a sector-based gap, and this logic is not specific to the Arab-Jewish case; it extends to other linguistic-minority, immigrant, and historically marginalized populations encountering similarly stratified science classrooms elsewhere (Aronson & Laughter, 2016; Bang & Medin, 2010). Situating DI within CVT in this way offers a conceptual lens that travels beyond the present context, treating competence and equity not as competing priorities but as outcomes of the same underlying pedagogical conditions.

In doing so, the study invites researchers, teacher educators, and policymakers to reimagine DI as a strategic lever for transforming science classrooms into places where all students can see themselves as capable and valued learners. Continued research into sustained, context-responsive models of DI will further strengthen the field's capacity to advance equitable and motivating chemistry education for diverse student populations.

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