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Research Article

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From screen to bench: unpacking the shifts in chemistry learning experiences during the COVID-19 transition

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Abstract: This research comprehensively analyzes students' Chemistry Learning Experience (CLE) during the COVID-19 pandemic, comparing online learning experiences with traditional face-to-face instruction in the post-pandemic phase. Employing a quantitative approach and leveraging the Rasch model, the study focuses on capturing the nuances of individual student perceptions, an aspect often overlooked in group-centric statistical analyses. One hundred students (49 males and 51 females) participated in both study phases. Segmented into behavioral tendencies, content perceptions, and specific learning needs, the evaluation tools provided insights into the students' CLE across the two instructional modalities. Results from the stacking analysis revealed a positive shift in CLE post-pandemic, with students demonstrating a better grasp of and attitude toward chemistry in face-to-face settings. Racking analysis further underscored the changing difficulty perceptions of specific content items across the two learning environments. Gender-based patterns in CLE were also evident, with male students expressing a more favorable view of online learning during the pandemic than their female counterparts. The research findings advocate for a blended learning approach, harnessing the strengths of both online and traditional instructional methods. Furthermore, insights into gender-specific learning experiences emphasize the need for inclusive and adaptive teaching strategies, ensuring optimal learning experiences for all students. The study underscores educators' and students' resilience and adaptability in navigating the challenges of the pandemic. It offers valuable insights for future educational strategies in chemistry education.

Keywords: Covid-19 pandemic; chemistry learning; chemistry curriculum; learning lost; perception of chemistry learning

1 Introduction

The Indonesian Ministry of Health confirmed the first official SARS-CoV-2 (COVID-19) case in Indonesia on March 3, 2020. Almost two weeks later, on March 12, 2020, the World Health Organization (WHO) declared the COVID-19 outbreak a global pandemic. In response to this escalating threat, the Indonesian Government announced on March 16 that all academic institutions, both public and private and spanning all educational levels, would close

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(Olivia et al., 2020). This decision affected institutions serving over 3.5 million students. Public venues like cinemas, theaters, and football stadiums were also mandated to close along with educational institutions, and this period witnessed an unprecedented disruption to Indonesia's educational ecosystem (Malik, 2022). Subjects such as chemistry, which intrinsically demand hands-on techniques and lab facilities, encountered significant hurdles in delivering an effective CLE (Chemistry Learning Experience) during this period (Qiang et al., 2020).

The COVID-19 pandemic catalyzed a profound shift in the educational paradigm with the rapid embrace of online learning. This digital-centric mode covers a spectrum of distance learning methodologies. As educational institutions globally adapted to this evolving scenario, online learning evolved from a stop-gap measure to a robust and structured educational strategy (Tigaa & Sonawane, 2020). Designed to function exclusively online, it is facilitated through platforms like Skype, Zoom, Google Meet, Webex, Microsoft Teams, and Slack (Soares et al., 2020). This approach, inherently reliant on the internet and electronic devices, offers many courses and content accessible remotely (Huang, 2020; Qiang et al., 2020).

The pandemic-induced shift necessitated a rapid pivot to online platforms for educators and students. Students' attitudes towards their CLE become instrumental in molding their learning behaviors in this milieu. This is particularly salient when contending with intricate chemical concepts (Cooper & Klymkowsky, 2013; Kalman et al., 2020). The nexus between how students perceive, engage, and internalize content directly influences their grasp of the subject. These attitudes can critically shape the nuances of the CLE. Amid the pandemic, many students were navigating the uncharted waters of online chemistry learning. This mode heavily leans on multimedia tools to elucidate complex chemical phenomena, such as atomic structures and molecular interactions (Sucre-Rosales et al., 2020).

Online distance learning accentuates high school students' inherent challenges in their CLE. It amplifies the subject's complexity, potentially eroding motivation, especially concerning foundational chemical concepts (Van Heuvelen et al., 2020). Past research has spotlighted students' struggles in deciphering abstract chemical notions and their challenges in interpreting chemical phenomena, especially when expressed through formulas and symbols. A significant impediment to online learning is the dearth of real-time interactions, potentially undermining the collaborative essence of learning (Jones et al., 2005; Supena et al., 2021). While some students flourish in such autonomous settings, others might find it overwhelming, feeling isolated and intimidated by the subject without structured classroom guidance. This heightened sense of autonomy, juxtaposed with the intricacies of chemistry, can exacerbate the perception of chemistry as an intimidating discipline (Pilkington & Hanif, 2021). For educators, the transition to virtual learning unveiled challenges in effectively conveying abstract concepts. They often use virtual tools to demystify chemical bonding and foundational concepts like stoichiometry (Mackenzie et al., 2012).

With the decline in COVID-19 cases and the proliferation of vaccination campaigns, there is a gradual swing back to face-to-face learning. Schools are transitioning from online modes to traditional classroom setups. It is intriguing to scrutinize how students' CLE during online sessions juxtaposes against their understanding in face-to-face setups (Chai & Tan, 2017; Pebriantika et al., 2021; Ryan & Norris, 2014). Delving into the experiences of students who engaged in online learning – which emphasized autonomous study and deciphered abstract concepts predominantly through virtual means – can provide enlightening insights. Observing their adaptability to direct classroom interactions and discerning potential shifts in their CLE, especially regarding concepts explored during online sessions, presents a captivating avenue warranting thorough exploration.

2 Literature review

2.1 Chemistry education: a unique challenge in remote learning

The essence of chemistry, which inherently necessitates hands-on experimental work, has been extensively documented (Savec & Mlinarec, 2021). This hands-on approach not only embeds a profound comprehension of theoretical constructs but also equips learners with the acumen to transpose this knowledge into tangible scenarios (Vilia & Candeias, 2020). The dichotomy between theoretical constructs and their practical manifestations in chemistry is pivotal. Though theoretical foundations scaffold the edifice of chemical principles, the practical applications breathe life into these tenets, accentuating their relevance (Ferreira et al., 2021). Despite the undeniable boon that practical exposure brings to the chemistry education tableau, it is not devoid of challenges. Orchestrating impactful laboratory experiments demands meticulous planning, especially with the omnipresent specter of safety concerns (Yeerum et al., 2022). Yet, the overarching consensus in academic circles, underscored by literature, remains unwavering: the rewards of experiential learning in chemistry eclipse the inherent challenges, offering learners an unparalleled, holistic pedagogical experience (Caraballo et al., 2021).

As underscored by literature, the absence of hands-on laboratory experiences profoundly impacts learning outcomes, with traditional labs providing a more immersive and tangible learning experience than their virtual counterparts (Brinson, 2015; Lindsay & Good, 2005). While digital simulations and virtual lab platforms have emerged as alternatives, they often cannot replicate the multisensory integration intrinsic to physical labs, such as tactile feedback (Cornelio et al., 2021; Viegas et al., 2018). Furthermore, technical constraints, including bandwidth limitations and the dearth of comprehensive virtual platforms, exacerbate the challenges of remote learning (Petillion & McNeil, 2020). To ensure meaningful scientific education in remote environments, addressing these obstacles and striving for a closer emulation of the holistic, hands-on laboratory experience is imperative.

Simulations, virtual labs, and at-home experiments using household materials have been acknowledged as pivotal in enhancing practical knowledge, especially in remote learning scenarios (Makransky et al., 2019). These tools simulate real-world lab experiences, allowing students to apply theoretical knowledge, make observations, and foster an understanding of scientific principles. Collaborative online projects further emphasize the theoretical aspects, promoting active learning and critical thinking. However, feedback highlights a preference among some students for traditional labs due to the tangible experiences they offer. The absence of physical interaction in virtual setups can occasionally impede comprehension of intricate chemical concepts. Thus, while digital tools and at-home setups provide innovative learning avenues, incorporating hands-on experiences remains crucial for a holistic chemistry education.

Educators transitioning chemistry education to an online format have grappled with significant pedagogical challenges, such as adapting hands-on experiments, fostering student engagement, rethinking assessment strategies, and ensuring equitable access to learning materials (Seery, 2015). Creative solutions have emerged, including implementing virtual labs, using online collaborative tools, devising alternative assessment methods, and offering course materials in diverse formats. While the shift has been demanding, these innovative approaches, like remote laboratory experiences and active learning strategies, can potentially enhance chemistry education even in post-pandemic traditional settings. Thus, despite initial challenges, the adaptations prompted by the online transition could yield lasting improvements in both digital and face-to-face educational contexts.

2.2 Gender disparities in remote learning

Gender dynamics in education are deeply rooted in historical disparities, leading to variations in learning approaches among male and female students. Research indicates that differences in social and behavioral skills between genders can result in gaps in educational attainment, which persist from early education into higher levels. The schooling environment, specifically the debate surrounding single-sex education, is one area that has been studied for its impact on these dynamics (Pahlke et al., 2014). Additionally, teacher gender has been shown to influence student achievement, with evidence suggesting that female primary school teachers might positively impact student outcomes (Antecol et al., 2015). In higher education, qualitative studies underscore the importance of subjective experiences in understanding gender disparities, with feminist and intersectionality perspectives offering deeper insights (Antecol et al., 2015; Molla & Cuthbert, 2014, 2018). Consequently, addressing these multifaceted gender dynamics is paramount to fostering a more equitable educational landscape.

Female students encounter many challenges in online learning, from socio-cultural responsibilities, limited access to resources, and psychological factors. Socio-cultural dynamics can impose gendered responsibilities and discriminatory practices that hinder their commitment to online education, as seen in scenarios like Hong

Kong, where socio-economic constraints limit access to study environments and tools (Mathrani et al., 2021; Yeung & Yau, 2021). Particularly in developing countries, the digital divide exacerbates disparities in access to technology and uninterrupted study time, further disadvantaging female students (Mathrani et al., 2021). Psychological factors like confidence and cultural influences on technology acceptance can also affect their participation and outcomes in online discussions (Bardakci et al., 2018; Khlaif et al., 2021). Addressing these multifaceted challenges is essential to fostering equitable online learning environments.

Male students in online learning often grapple with distractions, reduced focus, and, potentially, an aversion to seeking help due to the impersonal nature of digital platforms (Gopal et al., 2021). This shift to a relaxed remote environment can diminish their engagement and academic outcomes. Furthermore, adapting to self-paced learning can be challenging, with some facing issues like poor time management and lack of motivation, leading to procrastination (Xu & Jaggars, 2014). Feedback from both male and female students can offer invaluable insights into their online chemistry education experiences, aiding educators in customizing courses to cater to diverse needs. Analyzing performance metrics can spotlight gender disparities, guiding strategies to ensure equity in online learning environments.

Educators have implemented various strategies to address gender-specific challenges in online learning. Collaborative learning approaches, mentorship programs, and resources tailored to address gender-specific needs have been effective in promoting gender equity and creating inclusive learning environments (Laver et al., 2018; Schwerdtle et al., 2017; Spinner et al., 2021). Collaborative learning approaches have been recognized as effective in promoting gender equity in education by fostering cooperation, communication, and equal participation among male and female students. Mentorship programs provide guidance, support, and role models for students, particularly those who may face unique challenges based on their gender (Schwerdtle et al., 2017). Resources tailored to address gender-specific needs, such as online modules, videos, or interactive activities, have been developed to promote student awareness, understanding, and inclusivity (Spinner et al., 2021). These interventions and solutions support all students' academic success and well-being, regardless of gender.

3 Methods

3.1 Study design

This study employs a quantitative approach, comparing students' perceptions of their CLE during online sessions amidst the COVID-19 pandemic to their perceptions of returning to face-to-face instruction in the post-pandemic phase. Rasch analysis, leveraging stacking and racking techniques, is the chosen methodology for this research. Although various studies have delved into the pedagogies of imparting chemistry knowledge and gauged students' sentiments regarding the subject, the predominant analytical lens has been skewed toward group-centric statistics. Such methodologies often miss the finer nuances, overlooking individual student-level insights or eschewing a deeper understanding of the intricacy of specific content items. The current body of literature has not comprehensively captured students' experiences and perspectives when navigating the shift from online to face-to-face CLE.

3.2 Ethical approval

This research seeks to comply with the Declaration of Helsinki, and all participants involved in this study have agreed to express willingness to publish their data and have received approval from the Indonesian Ministry of Education and Culture. All participants in this research have agreed to fill out the instrument.

3.3 Participant

The study commenced in August 2021, with the participation of 523 science students from three schools in the Boyolali district. A preliminary survey was administered to assess the students' willingness to participate in a detailed examination of their "Chemistry Learning Experience". The research was divided into two main segments: the first focused on online learning during the pandemic, and the second focused on the resumption of face-to-face learning. Of the initial 523 students, 134 expressed interest in participating in both segments of the study. The first segment took place from August until September 2021, at the peak of the COVID-19 pandemic, where students shared their views on online chemistry learning through a questionnaire. As the severity of the pandemic diminished and traditional classroom learning resumed, the same group of students was revisited in May 2022 to answer the same questionnaire, aiming to identify any changes in their perceptions. Out of the 134 initial participants, only 100 continued through the study, with 34 students opting out before the commencement of the second segment. The final 100 participants consisted of a nearly equal gender distribution, with 49 males and 51 females completing the questionnaire.

3.4 Instrument

The evaluation tools employed in this study were meticulously standardized to assess students' attitudes toward their CLE. These tools were divided into three distinct indicators: the students' behavioral tendencies concerning their CLE, their perceptions about chemistry content, and their acknowledgment that certain chemistry content demands special focus or supplementary support (Cheung, 2009, 2011; Livak & Schmittgen, 2001).

The tool used for this research was structured around a five-point scale: 1 indicating disagreement and 5 signifying strong agreement with the statement. This tool revolves around three core indicators, each delving into different aspects of students' attitudes toward their CLE. These are Behavioral tendencies in the context of CLE, Perception of chemistry content, and Necessity for specialized focus or assistance during the learning process. As explained in Table 1, these indicators were adapted from Cheung (2011) research on student CLE. An added emphasis on the 'Perception of chemistry content' was incorporated to measure students' engagement and enthusiasm for the subject. The questionnaire, consisting of nine questions, was administered to the students on two occasions: firstly, during the zenith of the pandemic when learning was primarily online, and subsequently, post-pandemic, upon the resumption of face-to-face instruction. The sequence of the questions was shuffled for each administration to eliminate any sequence bias. Before the main execution of the study, the research instrument underwent a rigorous process of testing and validation to ensure its reliability and accuracy. Initially, a pilot test was conducted involving 60 students to assess the instrument's effectiveness and to make necessary adjustments based on the collected feedback. Additionally, the instrument was meticulously reviewed and validated by six experts in the field, ensuring that it met the essential criteria for a reliable and valid research tool. This comprehensive pre-testing and expert validation process resulted in the tool achieving impressive scores, with a reliability score of 0.89 and a validity score of 0.88, confirming its readiness for the primary implementation in the study.

3.5 Data analysis

The data procured from the questionnaire during the CLE in the online mode and the subsequent face-to-face mode underwent analysis. The amassed ordinal data was fine-tuned using the Rasch model approach. The raw data collected was initially processed to ascertain frequency, suggesting an odd probability. This probability was then transformed into data with equal intervals utilizing logarithms. The logarithmic function yields measurements on an equal interval scale, termed the logit scale, which boasts superior accuracy and precision compared to raw data. The Rasch model, proficient in gauging latent attributes, was employed to evaluate students' perceptions of their CLE across both online and traditional classroom settings. Stacking and racking techniques were deployed to juxtapose student person logit values during the CLE in the pandemic and the post-pandemic phases and the logit values of items (indicating the difficulty level of items) across the two contexts. The Rasch model can furnish individual-centric statistical insights by adjusting the logit values of individuals and items. This methodology stands apart from conventional inferential statistics, which generally elucidate the overarching scenario for the collective data but do not shed light on individual-level nuances. The contrasting scenarios before and after the tests are visualized using Wright's map, offering a holistic overview of the training's efficacy. Regression

Table 1: Students' attitude toward chemistry learning experience instrument.

Indicator	Number	Statement
Behavioral tendencies to study chemistry	1	I find chemistry intriguing and engaging.
	2	I appreciate chemistry because of its relevance to daily life.
	9	Before my chemistry classes, I engage in specific preparations, such as pre-lesson reading.
Perception of chemistry content	3	Visual representations of atoms, molecules, and chemical structures are clear.
	4	I find chemical symbols, equations, and formulas easy to remember.
	6	I find the calculations and mathematical aspects of chemistry straightforward.
Need special concentration/require help	5	I benefit from visual aids (e.g., images/videos) when studying chemistry.
	7	I believe chemistry requires high levels of concentration for proper understanding.
	8	I prefer explanations that incorporate visuals like pictures and animations in chemistry.

Table 2: Instrument's psychometric attributes.

Psychometric attribute	Pandemic	Post pandemic
Raw variance explained by measures	42.9	46.5
Unexplained variance	<15 %	<15 %
Cronbach's alpha	0.62	0.67
Person reliability	0.58	0.65
Person separation	2.11	1.89
Item reliability	0.95	0.96
Item separation	3.17	3.76

analysis between item logit values during the pandemic-era CLE and the post-pandemic CLE brings to light changes in skills associated with each item in the study (Table 2).

Rasch model analysis is a magnifying glass that can explore students' minds to understand their feelings towards chemistry. One of the magic spells is called LVP or Logit Value Person (Laliyo et al., 2022). By using LVP, educators can see students' confidence levels in subjects. If this magic number turns out to be positive, the student walks quickly, confident in his chemistry knowledge. However, a negative LVP is a sign that the student will trudge along, burdened by doubts and uncertainty about their understanding.

However, the Rasch model has another trick: LVI or Logit Value of Items. With LVI, educators can highlight specific questions or topics in the chemistry curriculum. A high LVI value was like a red flag, warning them that there was a dragon here – a topic many students found intimidating. Conversely, a low LVI is a green light, indicating an area where students feel comfortable, a topic they might discuss passionately in the cafeteria. Armed with insights from LVP and LVI, educators can begin their search. They now have a clearer map to navigate the vast landscape of chemistry education, ensuring their students learn and thrive (Mulyani et al., 2021).

4 Result and discussion

4.1 Stacking

Stacking analysis is a method used to combine or compare two or more datasets with the same dimensions or scales. This study employed stacking analysis to examine the differences in students' **Chemistry Learning Experience (CLE)** before and after the COVID-19 pandemic (Widyasari et al., 2018). The pre-pandemic data, collected when chemistry lessons were conducted face-to-face, was compared with the post-pandemic data, collected when learning had predominantly shifted to online methods. The Rasch model was employed to analyze both datasets, producing a logit value person (LVP) to reflect students' understanding of their CLE. A positive LVP suggests a more favorable experience, while a negative LVP indicates limitations in understanding.

Upon analysis, it was observed that the average LVP during the pandemic was +0.57 logit, indicating a relatively positive experience. This value increased to +0.85 logit post-pandemic, suggesting an improvement in students' CLE. The difference between these two mean LVPs was 0.28 logit, signifying a statistically significant change in experiences.

The Wright map was also utilized to provide a comprehensive view of students' experiences during and after the pandemic. Figures 1 and 2 display the LVP for male and female students, respectively. For instance, the LVP for male student A44 during the pandemic was 0.31 logit, which increased to 1.51 logit post-pandemic. This indicates a marked improvement in the student's CLE.

Female students also exhibited improved experiences, with most displaying increased LVP. The average difference between pre-pandemic and post-pandemic experiences for female students was 0.31 logit. The Wright map and stacking analysis offer insights into how students' experiences shifted, especially for female students, and how these experiences align with particular skill indicators. The comparison of pre-pandemic and post-pandemic data gives researchers a comprehensive understanding of the evolution of students' CLE. Pre-pandemic data serves as a benchmark, while post-pandemic data reveals the impact of the pandemic and the

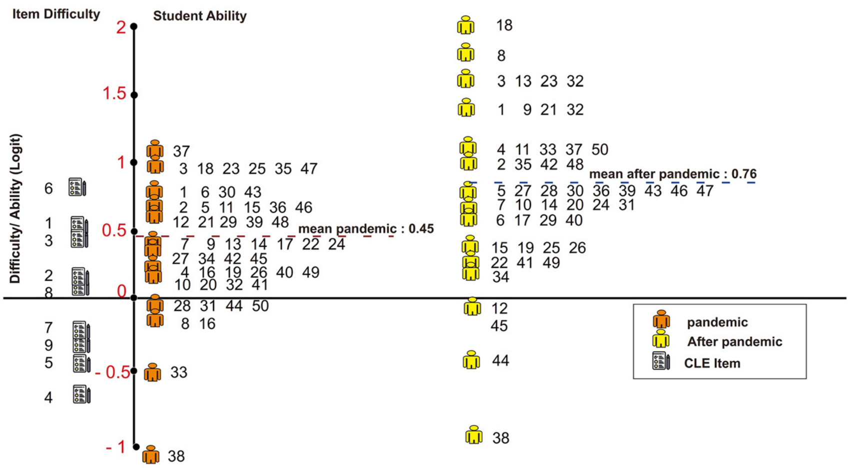

Figure 1: Wright map LVP of male students related to CLE: stacking.

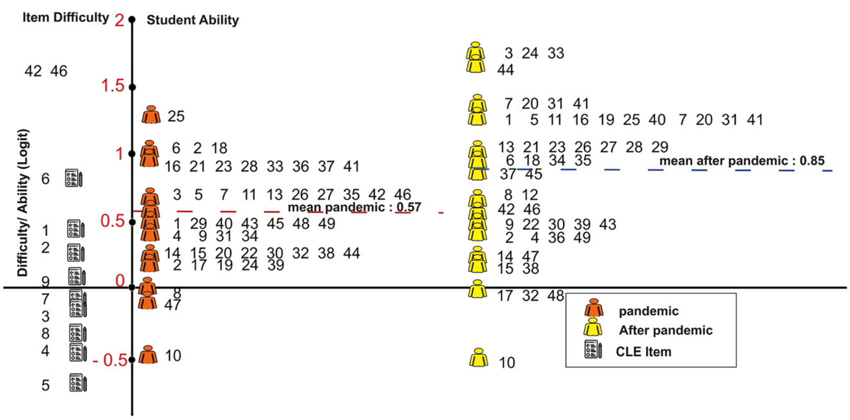

Figure 2: Wright map LVP of female students related to CLE: stacking.

shift to online learning (Adnan, 2020; Ali et al., 2020). This approach helps assess the pandemic's influence on educational experiences and offers insights that can guide the development of future educational strategies.

For male students' CLE during the pandemic, the logit value was +0.31. Post-pandemic, this decreased to −0.31 logit, marking a difference of about 0.62 logits, representing a significant shift in experience. This change indicates an enhanced CLE, as evidenced by the decline in the mean total LVI. Specifically, an improved CLE signifies that the learning environment became more effective and supportive, facilitating a better learning experience for the students. This positive transformation is corroborated by a decrease in the average total LVI, indicating that students were more motivated and involved in their learning journey post-pandemic.

4.2 Racking analysis

Racking analysis is a technique used to compare the difficulty level of individual questionnaire items or questions (Logit Value of Items – LVI) across two periods, in this case, before and after the onset of the COVID-19 pandemic. The primary goal of racking analysis is to identify changes in item difficulty and understand its relationship with the evolution of students' CLE.

Using the Wright map, the research team conducted a racking analysis to compare the LVI before and after the pandemic, dividing the data by gender. As depicted in Figure 3, the analysis for male students showed that the LVI for most items decreased by more than two logit scales from the during-pandemic to the post-pandemic phase. This drop in LVI suggests that returning to face-to-face learning improved male students' CLE, making chemistry content more understandable and engaging. Figure 4 shows the changes in LVI for female students. A significant observation is item A2, which examines the connection between chemistry and everyday life. During the pandemic, this item had an LVI of +1.2 logit, which changed to −0.32 logit post-pandemic. This considerable shift indicates that the understanding associated with this item saw significant improvement. Initially, students had difficulties understanding the relationship between chemistry and daily life. However, with the shift to face-to-face learning, this concept became clearer and more understandable (Adnan, 2020; Tigaa & Sonawane, 2020).

Racking analysis provides crucial insights into the dynamics of item difficulty levels and their relationship with students' CLE. The reduction in LVI after the pandemic indicates that returning to traditional, in-person learning positively impacted students' understanding and appreciation of chemistry. Identifying the items with the most significant changes offers insights into where students made the most progress in their understanding. These insights are invaluable for educators, allowing them to adjust their teaching methods and resources to enhance student's learning experiences and foster a more positive attitude towards chemistry education.

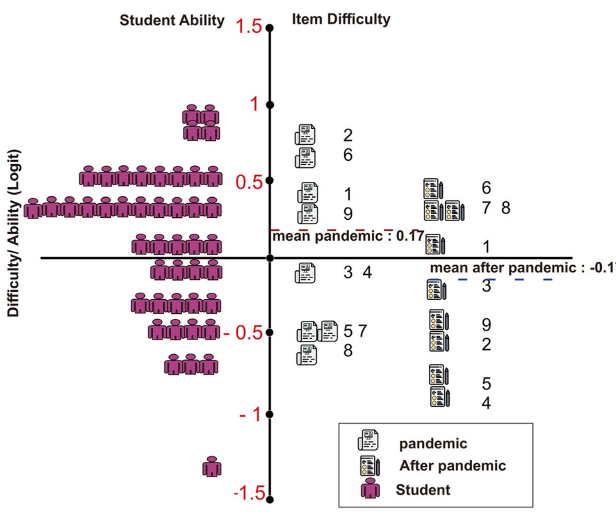

Figure 3: Wright map LVI of male student's chemistry learning experience (CLE): racking.

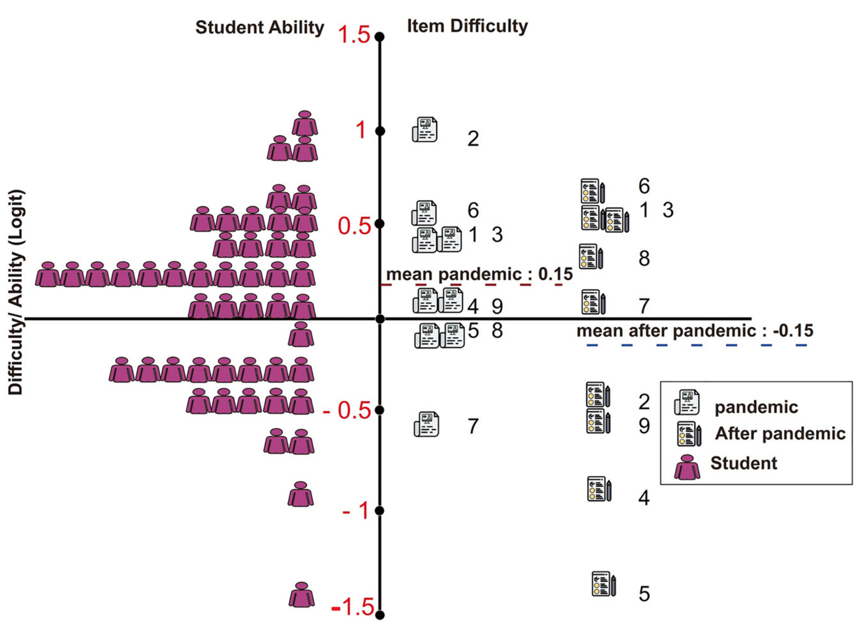

Figure 4: Wright map LVI of female students' chemistry learning experience (CLE): racking.

4.3 The difference in students' chemistry learning experience (CLE) during and after the pandemic

The stacking analysis highlighted distinct differences in students' CLE between the pre-pandemic and post-pandemic phases. During the pandemic, the sudden switch to online or hybrid learning modes was met with a more negative CLE. Students faced challenges adapting to this digital pedagogical shift, preferring traditional face-to-face instructional methodologies. Such unfavorable CLEs may have originated from limited resource accessibility, online communication challenges, and a lack of tangible laboratory experiences (Almazaydeh et al., 2016; Bond-Robinson & Rodriques, 2006).

However, as educational institutions transitioned back to face-to-face instruction post-pandemic, there was a noticeable improvement in students' CLE. The average logit value per person (LVP) increased from +0.57 during the pandemic to +0.85 afterward, indicating a more positive CLE. This positive shift could be attributed to the revival of direct, interactive learning, enhanced resource availability, and opportunities for hands-on laboratory activities. Several factors contributed to these contrasting CLEs across the two periods. The initial phase of the pandemic, with its unexpected focus on online learning, posed multiple challenges. Issues such as inconsistent access to technology, unreliable internet connectivity, and the lack of direct interactions might have hindered students' engagement and comprehension (Potkonjak et al., 2016; Siripongdee et al., 2020). Conversely, the post-pandemic return to traditional learning environments, characterized by direct interactions and hands-on experiences, likely enhanced students' CLE.

The insights from this study emphasize the importance of integrating authentic research experiences and real-world applications into the chemistry curriculum. This approach, supported by experiential learning, makes the subject matter more engaging and provides a deeper, practical understanding. This hands-on, applicative methodology can ignite students' enthusiasm and offer a more comprehensive grasp of chemistry concepts (Gani et al., n.d.). The study suggests a blended learning approach could be beneficial, seamlessly combining online and face-to-face elements. Such a teaching model provides the dual advantages of online convenience and the dynamic interaction of traditional classroom settings, catering to various learning preferences. The stacking analysis highlighted the noticeable shift in students' CLE as they faced the challenges of the pandemic and the subsequent return to standard learning methods. The findings stress the need for educators to be adaptable, weaving authentic research experiences and diverse instructional methodologies to create a more enriching and effective learning environment in the post-pandemic era.

4.4 The difference in CLE based on gender in online and face-to-face learning

The stacking analysis elucidated differences in the Chemistry Learning Experience (CLE) among male and female students during and after the pandemic. Gender-based patterns emerged, with male students demonstrating a more favorable view of online learning during the pandemic than their female counterparts. They appeared to navigate the digital learning environment more proficiently and expressed higher satisfaction with online instructional methods. Conversely, female students manifested a more adverse CLE of online learning during the pandemic, possibly encountering difficulties in engaging with the virtual classroom, accessing technology, or navigating online spaces comfortably. This divergence in CLE underscores the importance of comprehending and addressing gender-specific learning needs and preferences (Vilia & Candeias, 2020).

Post-pandemic, both male and female students displayed improved CLE with the resumption of face-to-face learning. Nevertheless, male students maintained a comparatively more positive CLE than female students. Male students may have readily embraced the transition to an interactive and collaborative learning environment (Green et al., 2021). The role of gender characteristics in influencing learning preferences and approaches to chemistry cannot be understated. Male students often prefer hands-on, kinesthetic learning experiences, enjoying activities that involve practical applications of chemistry concepts and opportunities for experimentation. In contrast, female students might gravitate towards collaborative and communicative learning environments, benefiting from discussions, group activities, and connections between chemistry concepts and real-world contexts. Understanding these gender-differentiated learning characteristics can guide educators in developing more inclusive and effective teaching strategies (Polat et al., 2022; Rachmatullah et al., 2018).

Addressing these gender-based disparities in CLE requires strategies that promote inclusivity and ensure equal opportunities for all students. Various learning activities – including hands-on experiments, group discussions, multimedia resources, and real-world applications – can cater to diverse learning preferences, ensuring both male and female students remain engaged and motivated in their learning journey (Aini et al., 2019; Levine et al., 2015). Creating an inclusive and psychologically safe classroom environment is critical in fostering active participation and cultivating students' interest in chemistry. Educators play an important role in cultivating this atmosphere, implementing strategies that encourage open discussions, collaborative activities, and the expression of diverse points of view without fear of judgment (Rachmatullah et al., 2018). Establishing norms of mutual respect and providing constructive, growth-focused feedback are important practices that strengthen a culture of mutual respect and inclusivity. Ongoing self-reflection by educators, focusing on recognizing and developing each student's unique strengths and contributions, will further improve the learning environment (Spinner et al., 2021). Adaptations to the curriculum and environment, such as modifying materials or using assistive technology, are also important to accommodate students with special educational needs, ensuring that each student, regardless of background or ability, can thrive in their chemistry education journey (Rachmatullah et al., 2018).

Educators play an important role in creating an inclusive learning environment in chemistry that supports and nurtures all students, regardless of gender. An important first step is to engage educators in actively confronting and mitigating ingrained biases or stereotypes, facilitated by ongoing self-reflection and professional development (Sunny et al., 2017; Van Bramer et al., 2001). Strategic initiatives such as mentorship programs and highlighting successful female role models in science can significantly influence and empower female students to pursue careers in chemistry and STEM (Levine et al., 2015). Equally important is establishing a strong support system that offers resources, guidance, and encouragement, assisting students in overcoming challenges and obstacles in their educational journey . In line with efforts to address the gender gap, a focus on improving CLE is essential, encouraging equitable participation and performance across genders (Lazarus et al., 2020). Incorporating mindful strategies such as active listening and cultivating opportunities for collaborative engagement further enriches the learning environment, ensuring each student feels valued and supported in their chemistry learning journey (Virginanti et al., 2019; Xiao et al., 2020). Through these joint efforts, educators can pave the way to a more inclusive, diverse, and thriving future for scientific communities.

4.5 Challenges of online and face-to-face learning

The onset of the COVID-19 pandemic precipitated a sudden transition to online CLE. This swift move to virtual platforms presented several challenges, necessitating students and educators to adjust to the new mode of instruction rapidly (Akhter et al., 2022). The situation was further exacerbated by inconsistent internet connectivity and limited access to necessary technological tools, impeding many from fully engaging in online CLE. The absence of face-to-face interactions, integral to traditional classroom settings, often led to feelings of detachment and difficulties in obtaining real-time clarifications. The virtual setup deprived students of hands-on laboratory experiences in chemistry, which is crucial for comprehending intricate concepts (Ferrell et al., 2019; Katchevich et al., 2013).

However, returning to face-to-face learning in the post-pandemic era brought several benefits. Direct engagements with educators and peers rekindled a sense of camaraderie and bolstered active involvement in the learning process. On-the-spot laboratory experiments and demonstrations greatly aided in understanding complex topics (Ferrell et al., 2019; Katchevich et al., 2013). However, this conventional mode of instruction was not devoid of challenges. Adherence to safety and social distancing guidelines sometimes restricted group activities and limited classroom dynamics. Additionally, some students, having acclimatized to the flexibility of online CLE, found it challenging to re-adjust to traditional classroom modalities.

To mitigate the drawbacks associated with online CLE, educators turned to a plethora of online collaboration tools, aiming to augment student engagement. Tailored feedback became pivotal, addressing individual learning trajectories (Koehler et al., 2020; Liu et al., 2019). The challenges intrinsic to face-to-face CLE catalyzed the emergence of a blended learning paradigm, harmonizing online and offline methodologies to enrich learning experiences while retaining requisite adaptability. Insights from the stacking and racking analyses underscore the imperative for an amalgamated educational framework. Even within brick-and-mortar classrooms, the continual infusion of technology remains paramount to heighten engagement and ensure students have unhindered access to premium educational content. Concurrently, safeguarding tactile experiences, particularly in laboratories, is indispensable for an all-encompassing understanding of subjects like chemistry (Adnan, 2020; Ching & Hursh, 2014). Going forward, an adaptable educational strategy, attuned to a spectrum of learning predilections and challenges, will set the blueprint for pedagogical practices. A relentless commitment to inclusivity, vouching for equitable access to top-tier education for everyone, will be a guiding principle.

4.6 Discussion of research findings

This research offers a comprehensive examination of students' perceptions regarding their CLE amidst the unpredictability of the COVID-19 era. Notably, a trend was observed where online learning was initially met with a less favorable perception, which subsequently shifted to a more positive stance upon the resumption of face-to-face instruction. These findings resonate with existing literature (Ali et al., 2020; Koseoglu & Pazurek, 2013), emphasizing the indispensable role of in-person interactions, particularly for a subject as nuanced as chemistry, which demands intricate conceptual understanding and hands-on engagement.

Blended learning has emerged as a promising strategy, synergizing the advantages of both digital and traditional instructional methods (Nada & Sari, 2020). By harnessing the strengths of each modality, educators can curate a more enriching and adaptable CLE. Infusing the curriculum with hands-on research opportunities and real-world applications deepens students' grasp of chemistry and accentuates the subject's real-world significance, fueling their enthusiasm and curiosity. Insights from this study also shed light on differences in CLE based on gender, highlighting the imperative for an inclusive educational approach that champions equality and representation (Permatasari et al., 2022).

However, it is crucial to acknowledge the study's limitations. Given the specific demographic focus, the findings might not be universally applicable across varied populations and regions, each potentially possessing unique CLE dynamics. The reliance on self-reported data might also introduce certain biases (Johnstone, 2009; Stieff, 2011). Future studies could adopt a mixed-methods framework for a more holistic perspective, amalgamating quantitative analyses with qualitative insights from interviews or focus groups. The challenges and adaptations prompted by the pandemic underscore the pivotal role of direct, face-to-face engagement in nurturing a favorable CLE, especially in multifaceted subjects like chemistry (Adnan, 2020; Cann, 2016). These revelations champion the cause of blended learning, inspiring educators to sculpt a vibrant and attuned CLE to individual student needs. Equipped with the insights from this research, educators, policymakers, and academic institutions are better poised to steer the post-pandemic educational landscape, ensuring every student is privy to an optimal CLE.

5 Conclusions

The education landscape underwent a dramatic transformation due to the COVID-19 pandemic, prompting an expedited shift to digital platforms for educators and students. This study meticulously probed the ramifications of these abrupt changes on students' CLE (Chemistry Learning Experience). Harnessing stacking analysis, in conjunction with Rasch models and Wright maps, this research assiduously mapped the trajectory of student perceptions during and after the pandemic. The findings spotlighted genuine apprehensions surrounding online learning during the pandemic and accentuated the intrinsic merits of face-to-face instruction. The post-pandemic phase witnessed a revival in students' CLE, underscoring the salience of direct human interaction, especially in subjects like chemistry, which intrinsically demand hands-on applications. The survey results champion a harmonized educational approach, amalgamating the virtues of online and traditional learning paradigms and reinforcing the blended learning paradigm. Such a comprehensive approach promises to be the bedrock for an educational future fortified against unforeseen challenges. Delving into gender-specific data offers intriguing revelations. While male and female students registered enhancements in their CLE post-pandemic, female students exhibited more pronounced progress. These disparities underscore the imperative to address dormant gender biases in our educational architecture, stressing the need to carve out equitable learning spaces, particularly for women aspiring to STEM careers. Anchoring the chemistry curriculum in real-world contexts and experiential learning emerges as paramount. Empirical data substantiates that intertwining theoretical insights with tangible applications cultivates progressively deeper learning experiences. Although this research presents a panoramic view, acknowledging inherent limitations is crucial. The circumscribed demographic lens and potential biases in self-reported data necessitate judicious interpretation of the findings. Broadening the research scope to encompass diverse student demographics and infusing qualitative insights might offer a more nuanced comprehension. This investigation stands as a guiding light, illuminating the path forward for CLE in the post-pandemic era. It emphasizes the indispensability of blended learning, gender inclusivity, and immersive engagement. As we navigate this post-pandemic trajectory, such insights will be instrumental in sculpting an inclusive, dynamic, and adaptive educational milieu wherein every student flourishes irrespective of their background.

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