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EVALUATING THE LEARNING CURVE OF A NOVICE OPTOMETRY STUDENT IN SCLERAL LENS FITTING: A PROSPECTIVE QUANTITATIVE STUDY USING DELIBERATE PRACTICE AND CUMULATIVE SUMMATION (LC-CUSUM)

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ABSTRACT

Background and Objective: To evaluate the learning curve of a novice optometry student in scleral lens fitting through deliberate practice and to objectively quantify the learning process using the Learning Curve-Cumulative Summation (LC-CUSUM) test, ensuring accurate and unbiased results.

Method: The complexity of scleral contact lens fittings was assessed by categorizing subjects into regular and irregular cornea groups. A student enrolled in the Master of Optometry program conducted the fittings using a dedicated scleral lens record form (rubrics) designed to quantify the lens management approach. Prior to performing fittings independently, the student received four weeks of training from a contact lens expert, who also served as her guide for the study. This training period and the subsequent fittings were structured based on the principles of deliberate practice, with the student performing repeated diagnostic trials. A maximum of three diagnostic trials were performed for each subject to achieve the optimal fit. After each trial, the student completed a self-efficacy scale questionnaire to assess her perceived difficulty and clinical judgement skills, recording "FIRST trial scores" following the initial trial and 'LAST trial scores' after achieving the optimal fit. The guide consistently provided verbal feedback after each case throughout the fitting process as part of the deliberate practice methodology to enhance the student's understanding of the fitting procedure while keeping the scores confidential to ensure unbiased self-assessment. Following the complete supervision of the fitting procedure, the guide evaluated the student's clinical skills using a specially designed observation scale questionnaire, referred to as the 'GUIDE scores.' A seven-point Likert scale was used to rate the judgement for both the self-efficacy scale and observation scale questionnaire. The student's LAST trial scores were subsequently compared with the GUIDE scores.

Results: A total of 80 scleral lens fittings were evaluated. The Intraclass Correlation Coefficient (ICC) demonstrated excellent agreement between student-reported self-efficacy scores and guide-reported observation scores. The difference in self-efficacy scores between the initial and final lens fittings was statistically significant ($p < 0.05$), as determined by the Wilcoxon signed-rank test. The Learning Curve-Cumulative Summation (LC-CUSUM) chart revealed that learning stabilized after 26 fittings, marking a consolidation phase where minimal further improvement was observed beyond this point, and additional practice primarily helped to maintain proficiency. The average number of trials required per eye was higher in patients with irregular corneas than those with regular corneas.

Conclusion: This study evaluated the learning curve of a novice optometry student in scleral lens fitting through deliberate practice, utilizing the LC-CUSUM test to quantify progress and assess skill acquisition objectively. Proficiency was achieved after 26 fittings, with additional trials needed for irregular corneas, underscoring the influence of patient characteristics on learning. These findings emphasize the importance of structured training, personalized feedback, and self-assessment in developing clinical competence. The insights contribute to advancing education and research in contact lens science by providing practical guidance for designing effective programs focused on planning, teaching, and learning about scleral lens fittings.

Keywords: Novice Optometry Student, Scleral Lens Fitting, Deliberate Practice, Learning Curve, LC-CUSUM

INTRODUCTION

Scleral contact lenses (SLs) were first developed in 1887, and gas-permeable (GP) SLs were introduced in the early 1980s. Since then, SLs have been primarily utilized by eye care practitioners in tertiary care centres or specialized contact lens practices to manage severe ocular conditions.[1] Extensive interest in SLs has significantly increased during the last decade. Their prescription has also expanded into community eye care practices due to their material advancements, increased commercial availability, and broader indications for their use in correcting various refractive errors in cases with regular corneas and significantly enhancing the visual quality in complicated and advanced cases.[2]

For the most part, fitting assessment of SLs is subjective and lacks a consensus.[3] Recommendations from contact lens manufacturers and practitioners vary widely; this could confuse an emerging practitioner.[4] A comprehensive literature search revealed a scarcity of peer-reviewed studies on student learning. A single study on the practitioner learning curve, a prospective dispensing case series, was identified. This study demonstrated a significant decrease in trials and reorders needed after the initial 60 cases.[5] The current study aimed to evaluate the learning curve of a novice optometry student in SL fitting through deliberate practice, and to objectively quantify the learning process using the Learning Curve-Cumulative Summation (LC-CUSUM) test, ensuring accurate and unbiased results.

K. Anders Ericsson conceptualized deliberate practice (DP) as a structured, focused approach to developing expertise. It involves targeted practice sessions, guided by mentors or coaches, designed to enhance specific skills.[6] DP focuses on a well-defined area, requiring learners to move beyond their comfort zone with sustained attention and effort. This method helps develop and refine mental representations, progressively improving with continued practice.[7]

Establishing a learning curve is critical for ensuring quality assurance and patient safety in medical procedures. The LC-CUSUM test monitors performance during the initial learning phase and confirms proficiency upon reaching a predefined threshold. Post-proficiency, continued performance is monitored using the CUSUM test. These tools are widely applied across medical fields, including obstetrics and gynecology, to assess proficiency in complex procedures like fetoscopic laser surgery and ultrasound diagnostics.[8]

METHODOLOGY

This prospective, quantitative study adhered to the tenets of the Declaration of Helsinki and was approved by the NHL Institutional Review Board (NHLIRB). This study was conducted at the Contact Lens Department of Shree C. H. Nagri Municipal Eye Hospital, Ahmedabad, from May 2019 to March 2020. A student enrolled in the Master of Optometry program conducted the fittings using a dedicated SL record form (rubrics) designed to quantify the lens management approach. A novice student recruited 47 subjects to participate in a scleral contact lens fittings study. The lenses were sourced from No. 7 Contact Lens Laboratory, UK, with additional technical specifications detailed in Table 1. Two trial sets were utilized: one comprising standard design lenses (13 trial lenses) and another featuring toric periphery and reverse geometry designs (24 trial lenses). Both sets comprised lenses with standard lens diameter of 15mm but different parameters.

TABLE 1 Technical Specifications of the Trial Lens Sets.

Material	Optimum extra (Roflucon D; blue & clear color)
Dk	100
Sag	3400 to 5100 in 20 micron steps
Power	+25.00D to −25.00D (0.25 steps)
Wearing schedule	Daily
Replacement	Annual
Central thickness	0.20 mm (200 um)
Refractive index	1.431D
Hardness	75
Contact angle	3
Scleral opening	65 degrees

Participants were divided into two major groups: The irregular cornea (IC) and the regular cornea (RC) groups. The IC group included subjects with keratoconus, pellucid marginal degeneration, post-radial keratotomy, post-LASIK ectasia, post-penetrating keratoplasty, and high irregular astigmatism. The RC group consisted of subjects with moderate to high refractive errors, such as myopia (≥ 6.00 D), astigmatism (≥ 2.00 D), hyperopia (≥ 4.00 D), and those who were dissatisfied with rigid gas-permeable (RGP) lenses or had discontinued their use. Written informed consent was obtained from all recruited subjects. Exclusion criteria included active corneal pathology, ptosis, palpebral aperture ≤ 7 mm, retinal pathology resulting in poor vision, and refusal to provide written consent.

Prior to conducting the fittings independently, the student received training on fitting procedures for four weeks on 20 eyes with RC of peers from a contact lens expert, who also served as her guide for the study. This training period and the subsequent fittings were structured based on the principles of DP, with the student performing repeated diagnostic trials. After each trial, the student completed a self-efficacy scale questionnaire to assess her perceived difficulty level and clinical judgement skills. Following the complete supervision of the fitting procedure, the guide rated the student's clinical skills using a specially designed observation scale questionnaire. A seven-point Likert scale was used to rate the judgement for both the self-efficacy scale and observation scale questionnaire: (1) Extremely difficult, (2) difficult, (3) little difficult, (4) neither difficult nor easy, (5) little easy, (6) easy, (7) extremely easy.

The following stepwise fitting evaluation approach was implemented in each case:

1. Initial assessment: This involved an evaluation of the ocular condition using a slit lamp, patient counseling on suitable lens options, and obtaining informed written consent.
2. Primary SL work-up: The lens was selected and applied based on sagittal curvature

maps from corneal topography to determine the type and location of corneal irregularities, guiding the choice of the appropriate trial lens sag. The Comfort 15 trial set guidelines were followed, and the application time was recorded. A SL settling time of 60 minutes was incorporated across all cases to ensure consistent evaluation.

3. Post-fit assessment: Fluid reservoir measurements were compared and quantified using a slit lamp and anterior segment optical coherence tomography (AS-OCT). This was followed by lens removal, with removal time recorded.
4. Necessary trials: In cases where the initial fit was not optimal, a second or, if required, a third diagnostic trial was conducted until the student achieved the optimal fit.
5. Scoring process: After each trial, the student completed a self-efficacy scale questionnaire to assess her perceived difficulty and clinical judgement skills, recording 'FIRST trial scores' following the initial fitting and 'LAST trial scores' after achieving the optimal fit. The guide provided verbal feedback consistently after each case throughout the fitting process, as part of the *DP* methodology to enhance the student's understanding of the fitting procedure, while keeping the scores confidential to ensure unbiased self-assessment. Following the complete supervision of the fitting procedure, the guide evaluated the student's clinical skills on the optimal fit using a specially designed observation scale questionnaire, provided the scores referred to as the "GUIDE scores" (Figures 1 and 2).

Fitting Goals

(A) A central fluid reservoir of 300 µm, confirmed through the slit lamp examination (B) A limbal fluid reservoir of 50 µm, also assessed via slit lamp examination (C) Confirmation of central and limbal fluid reservoir using AS-OCT (D) complete overall limbal clearance (E) even scleral lens centration and alignment (F) optimal SL edge alignment without bubble and impingement (G) vision with the best corrected SL over-refraction of ≥ 6/9 for distance and ≥ N8 for near, as assessed using Snellen charts.

Statistical Analysis

Data were managed and analyzed using Microsoft Excel spreadsheet (Microsoft, Redmond, WA), and statistical analysis was conducted using SPSS version 26.0 (IBM Co, IL). The level of statistical significance was set at $p < 0.05$. The tests conducted included - Intraclass Correlation Coefficient (ICC), Wilcoxon signed-ranked test, and The Learning Curve-Cumulative Sum (LC-CUSUM) chart. Learning curve analysis for pellucid marginal degeneration could not be performed due to the presence of only one subject.

RESULTS

SL trials were conducted on 80 eyes from 47 subjects (27 male), aged between 11 and 80 years. Insertion time decreased from 90 seconds initially to 10 seconds by the final fittings, with an average of 21.19 seconds (SD = 19.37) and a reduction of 1.81 seconds per fitting. Similarly, removal time decreased from 56 seconds to 2 seconds, with an average of 9.48 seconds (SD = 11.20) and a reduction of 0.99 seconds per fitting. Although the Wilcoxon signed-rank test found no significant difference between right and left eyes for insertion ($p = 0.22$) or removal times ($p = 0.75$), the overall trend demonstrated clear improvement in the student's proficiency with practice.

The ICC was calculated as two raters were involved, to assess agreement between the student's last self-efficacy scores and the guide's observation scores. Given the continuous nature of the data, ICC was selected as the appropriate metric, analyzed using SPSS 26 Software with a "Two-Way Mixed Effect Model" and "Type - Absolute Agreement" to

Self – Efficacy Scale for Scleral Lens Fitting – by student

Likert Scale on basis of difficulty

[1 - Extremely difficult, 2 - difficult, 3 - little difficult, 4 - neither difficult nor easy, 5 – little easy, 6 - easy, 7 - extremely easy]

PATIENT'S NAME: **TRIAL No:**

	1	2	3	4	5	6	7
1. Assessing the corneal condition on Slit lamp							
2. Understanding the visual requirements and lifestyle of patient then counselling for scleral contact lens trial							
3. Application of elevation map from topography reports for selection of 1st trial lens							
4. Determining the sagittal depth of lens for 1st trial fit							
5. Application of the lens with fluorescein							
(a) Special comments on fluorescein pattern							
(b) Organizing aseptic environment							
6. Post fit overall slit lamp examination							
7. Determining correct thickness of fluid reservoir for optic zone							
8. Determining correct thickness of fluid reservoir for limbal zone							
9. Assessment of landing zone							
10. Assessment of edge profile							
11. Determining the over-refraction post 60 minutes							
12. Removal of the lens							
(a) comment on force required to remove the lens with plunger							
13. Determining necessary parameter changes to achieve successful fit							
14. Overall impression of completing a trial							
15. Overall confidence while doing the lens fitting procedure							

FIGURE 1 Self-efficacy scale questionnaire.

Observation Scale for Scleral Lens Fitting – by Guide

Likert Scale on basis of difficulty

[1 - Extremely difficult, 2 - difficult, 3 - little difficult, 4 - neither difficult nor easy, 5 – little easy, 6 - easy, 7 - extremely easy]

PATIENT'S NAME: **TRIAL No:**

	1	2	3	4	5	6	7
1. Assessing the corneal condition on Slit lamp							
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9. Assessment of landing zone							
10. Assessment of edge profile							
11. Determining the over-refraction post 60 minutes							
12. Removal of the lens							
(a) comment on force required to remove the lens with plunger							
13. Determining necessary parameter changes to achieve successful fit							
14. Overall impression of completing a trial							
15. Overall confidence while doing the lens fitting procedure							

FIGURE 2 Observation scale questionnaire.

ensure precise measurement of agreement between the two sets of ratings.

The ICC values ranged from 0.851 to 0.980, indicating excellent reliability. Regular cornea, keratoconus, and post-penetrating keratoplasty conditions showed ICC values above 0.939, confirming excellent agreement, while post-LASIK ectasia (0.878) and post-radial keratotomy (0.851) demonstrated good reliability. All values were statistically significant, with 95% confidence intervals (CI) confirming the strength of agreement. Wider CIs for post-LASIK ectasia, post-radial keratotomy, and post-penetrating keratoplasty, due to smaller sample sizes, still confirmed good to excellent agreement, with lower bounds at 0.698, 0.671, and 0.771, respectively (Table 2).

Further analysis using the Wilcoxon signed-rank test compared the student's first trial scores with the last trial scores, and the difference in scores was statistically significant ($p < 0.05$). Thus, the student in this study achieved proficiency in the clinical skill of fitting SLs.

The Learning Curve-Cumulative Summation (LC-CUSUM) chart, a recognized statistical tool for process control and performance monitoring, tracked the student's progress. The learning curve, representative of procedural skill acquisition, depicted the average cumulative sum of SL trials across different corneal conditions, highlighting the student's mastery of the fitting process.

TABLE 2 Intraclass Corelation Coefficient Indicating Agreement between Student and Guide Scores.

Type of cornea	No of patients	ICC (95% CI)
Regular	14	0.980 (0.974–0.985)
Keratoconus	21	0.968 (0.959–0.974)
Post-LASIK ectasia	3	0.878 (0.698–0.942)
Post-radial keratotomy	3	0.851 (0.671–0.926)
Post-penetrating keratoplasty	5	0.939 (0.771–0.975)

There was minimal improvement in the initial phase (0–5 patients), with the average cumulative sum remaining at 0, reflecting the development of foundational skills and no significant proficiency achieved.

During the rapid learning phase (6–20 patients), the CUSUM rose sharply from 1.0 (6th patient) to 6.3 (19th patient), reflecting *accelerated skill acquisition*. Complex cases such as keratoconus and post-surgical corneas resulted in the steepest increases, while regular corneal cases showed more gradual gains. Notable rises occurred with the 7th patient (keratoconus, CUSUM 2.1), 13th (post-LASIK ectasia, CUSUM 4.5), and 15th–16th (post-penetrating keratoplasty, CUSUM 5.2, 5.3), emphasizing the role of challenging cases in learning progression. Details on specific corneal conditions are provided in Table 3.

In the plateau phase (21–26 patients), Following the 20th patient, the curve plateaued at CUSUM 7.5 (26th patient), indicating the student had reached a high level of competence with minimal improvement beyond this point. Exposure to both regular and complex cases contributed to this stabilization.

In the late phase (27–47 patients), following exposure to 26 patients, the student's skill improvement plateaued. At this stage, the student was deemed proficient, with additional practice primarily serving to maintain her skill level rather than driving significant further advancement. This suggests that the learning curve had reached a phase where additional experience did not significantly change the number of trials needed for successful fittings. The average number of trials required per eye was higher in patients with irregular corneas than those with regular corneas (Figure 3, Table 3).

DISCUSSION

This study evaluated the learning curve of a novice optometry student in SL fitting through DP, utilizing the LC-CUSUM test to quantify progress and assess skill acquisition objectively. As the first prospective study applying LC-CUSUM to analyze

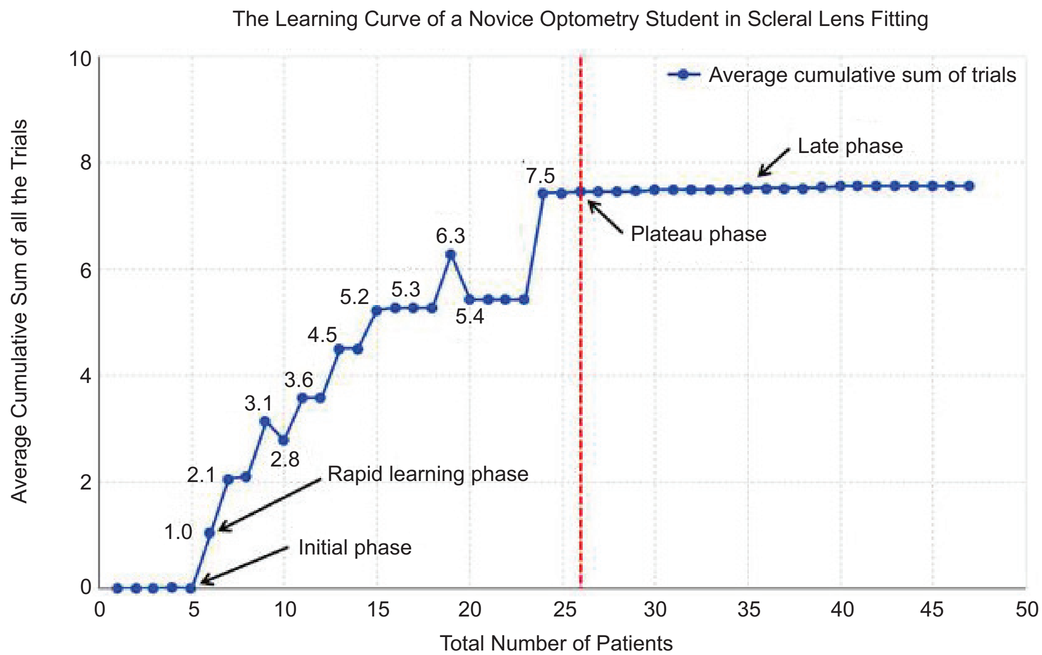

FIGURE 3 Cumulative sum chart.

TABLE 3 Observations Corresponding to Upward Slopes in the Learning Curve.

Observation (Trials)	Average Cumulative Sum	Eye	Cornea Group	Clinical Characteristics
6th	1.0	Left	Irregular	First patient with post-penetrating keratoplasty surgery
7th	2.1	Left	Irregular	Second patient with keratoconus
9th	3.1	Left	Regular	Fourth patient with a normal cornea
10th	2.8	Right	Irregular	First patient with radial keratotomy
11th	3.6	Right	Regular	Fifth patient with a normal cornea
13th	4.5	Right	Irregular	Second patient with post-LASIK ectasia
15th	5.2	Left	Irregular	Second patient with post-penetrating keratoplasty surgery
16th	5.3	Left	Irregular	Third patient with post-penetrating keratoplasty surgery
19th	6.3	Left	Irregular	Fifth patient with keratoconus
20th	5.4	Right	Irregular	Sixth patient with keratoconus
26th	7.5	Left	Irregular	Ninth patient with keratoconus

a novice's learning curve in SL fitting across various corneal conditions, it fills a gap in existing research. Despite reports of steep learning curves in SL fitting, prior studies have not examined the specific challenges novices face, highlighting the importance of the fitting trial method in fostering proficiency.[5]

Factors such as goal setting, information processing, rewards, and teacher feedback significantly influence students' motivation, helping them monitor progress and maintain self-efficacy as they gain proficiency.[9] In healthcare education, acquiring procedural competence remains challenging.[10] Primary health educators address this by promoting academic self-efficacy through metacognitive strategies, such as self-testing and self-monitoring, which enhance students' judgement skills and foster independent learning.[11]

DP is fundamental for acquiring and refining complex skills, especially in medicine, where structured and sustained practice with targeted feedback is critical for achieving superior performance. Proficiency develops through repeated, focused practice that builds on prior knowledge and forms mental models for problem-solving and skill evaluation. At advanced stages, these models enhance learning efficiency, easing the acquisition of new skills. Continuous practice in feedback-rich environments maintains and improves performance, strengthens individual skills, and enhances diagnostic accuracy and treatment outcomes. Research shows that DP sustains high performance throughout a professional's career, even with aging, challenging the notion that performance declines over time.[12]

Specifically, specialized questionnaires were developed to evaluate the learning process in SL fitting using the principles of DP. The questionnaires evaluated each step of the fitting process—from lens application through fit evaluation before and after SL settling to lens removal. After each trial, the student completed a self-efficacy questionnaire with a Likert scale to assess the perceived difficulty and clinical judgement. Meanwhile, the guide provided consistent verbal feedback after each case, in line with DP methodology, enhancing the student's understanding while keeping scores confidential to promote unbiased self-assessment. Following supervision of the complete fitting process, the guide completed an observation scale questionnaire to assess the student's ability to achieve the optimal fit, rating it on a Likert scale (see Figures 1 and 2).

If the first diagnostic trial was not optimal, a second, and when required, the third trial was conducted. The student recorded 'FIRST trial scores' after the initial attempt and 'LAST trial scores' after achieving the optimal fit, while the guide provided 'GUIDE scores' for the final fit. The statistical analysis demonstrated a significant improvement ($p < 0.05$) between the student's first and last scores, verified through the Wilcoxon signed-rank test. Additionally, the ICC indicated excellent agreement between the student's LAST scores and GUIDE's scores, confirming that proficiency was achieved under complete supervision, ensuring corneal health and restoring functional vision.[13]

The LC-CUSUM has been widely used in human medicine to assess clinical proficiency,[14,15] addressing limitations of other methods like the exponentially weighted moving average and risk-adjusted CUSUM. Its adaptable parameters (target value, control limits, and average run length) make it suitable for evaluating diverse procedures at varying performance levels. Trainees demonstrating proficiency may perform tasks independently, with continuous monitoring via personal log books, and supervision ceasing upon consistent performance.[16]

In medical education, CUSUM focuses on evaluating outcomes rather than the process of skill execution. Although this study emphasized *formative assessments* through training, feedback, and discussion, achieving and declaring competence still aligns with the goal of *summative assessment.* The student's learning curve for SL fitting followed the expected pattern, with a rising CUSUM curve, the so-called *learning curve*. The student's mastery of the new skill was indicated when the curve eventually flattened (no slope).[17]

Theories of self-regulated learning follow a continuous cycle of reflection, task engagement, self-monitoring, and adjustment.[18] Learning curves enhance this process by visualizing progress, facilitating reflection, and guiding performance improvements. They highlight past achievements and expected outcomes, fostering strategic learning and self-monitoring.[19–21] Furthermore, the learning curve model, where effort leads to goal attainment, applies across health education contexts, reinforcing growth mindsets associated with resilience and long-term success.[22]

This study provides valuable insights into designing targeted educational interventions to enhance novice students' efficiency and shorten learning phases. A novice student achieved competency in SL fitting after 26 consecutive fittings involving 80 eyes. Early learning was marked by a rapid rise in trials, with more attempts required for irregular corneas, emphasizing the role of patient characteristics in learning. The learning curve plateaued after the 26th patient, indicating a consolidation phase where further practice maintained skill levels without significant improvement. This pattern highlights the importance of understanding learning variability and tailoring educational strategies accordingly.

Clinical proficiency has traditionally been assessed using subjective criteria, such as an arbitrary number of attempts or a fixed training duration, assuming proficiency over time.[23] However, these generalized assessments often overlook individual variability in learning and the need for continuous evaluation to maintain proficiency.[24]

In contrast, this study demonstrates that LC-CUSUM effectively generates personalized learning curves, offering a tailored approach that accounts for individual variability in skill acquisition. The findings emphasize the importance of structured training, personalized feedback, and self-assessment in developing clinical competence and accurate proficiency assessments, replacing arbitrary measures with data-driven evaluations. This analysis provides practical insights for planning, teaching, and learning SL fittings.

DP, involving repeated trials, consistent feedback, and reflection, was pivotal in refining the student's clinical judgement, aligning with self-regulated learning principles. Confidential scoring and verbal feedback from the guide ensured unbiased self-assessment, while LC-CUSUM provided objective benchmarks across different stages of training. These findings highlight the value of incorporating diverse teaching methods, including computer simulations, mannequin models, and live models, to enhance training outcomes and develop skilled practitioners in optometry.[25]

LIMITATIONS

This study examined the learning curve of a single novice optometry student, limiting the generalizability of findings to a broader population and preventing comparisons of learning styles and progress rates among different individuals. Using diagnostic sets from a single manufacturer restricts insights into how lens design variations may influence learning. Furthermore, although the study included diverse corneal conditions, it did not explore comparative learning outcomes across these groups. Future research could address these limitations by including multiple students and diagnostic sets from various manufacturers and analyzing learning curves across different corneal conditions to provide a more comprehensive understanding of skill acquisition in SL fitting.

CONCLUSION

This study evaluated the learning curve of a novice optometry student in SL fitting through DP, utilizing the LC-CUSUM test to quantify progress and assess skill acquisition objectively. Proficiency was achieved after 26 fittings, with additional trials needed for irregular corneas, underscoring the influence of patient characteristics on learning. These findings emphasize the importance of structured training, personalized feedback, and self-assessment in developing clinical competence. The insights contribute to advancing education and research in contact lens science by providing practical guidance for designing effective programs focused on planning, teaching, and learning about SL fittings.

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