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ORIGINAL RESEARCH

# Exploring the Use of Visual Thinking Strategies in Dental Education for Radiographic Assessment of Root Canal Obturation

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**Abstract**
This study investigated the impact of visual thinking strategies (VTS), an art-based visual training method, on dental students' skills in radiographic interpretation, specifically evaluating root canal obturation. Despite the critical role of radiographic imaging in endodontic care, dental curricula typically assume observational skills rather than explicitly training them. A quasi-experimental mixed-methods design involved 90 third-year dental students, with 50 participating in structured VTS training sessions utilising selected artworks rich in visual details and interpretive complexity. The remaining 40 students served as a control group. Following VTS training, both groups assessed the quality of 198 periapical radiographs using a checklist-based scoring system aligned with the European Society of Endodontology guidelines. Ratings from an expert panel provided a consensus standard. Statistical analyses revealed that VTS-trained students produced radiographic assessments significantly closer to expert evaluations compared to untrained peers (median: trained group = 2.54; untrained group = 2.70; specialists = 2.50). Intraclass correlation coefficients showed substantial agreement between trained students and specialists (ICC = 0.878) versus lower agreement among untrained students (ICC = 0.799). Qualitative feedback indicated that VTS enhanced students' abilities to observe subtle details, interpret complex visual information, and consider multiple perspectives, reflecting improved visual diagnostic reasoning. However, some students expressed uncertainty regarding direct clinical applicability. These findings suggest that structured VTS training can meaningfully enhance observational and interpretive skills critical for radiographic assessment in dentistry, recommending further integration and evaluation of such art-based methods within dental education.

**Keywords** Dental materials · Mechanical properties · Polymethyl methacrylate · Recycling · Sustainability

## Introduction

In endodontic diagnosis and treatment evaluation, dental practitioners are required to observe, interpret, and make decisions based on radiographic images. Root canal obturation is the procedure where cleaned and disinfected root canals within a tooth are filled and sealed to prevent reinfection [1]. Accurate radiographic evaluation of this procedure is critical because inadequately sealed canals can lead to treatment failure and subsequent reinfection or tooth loss [2]. However, interpreting radiographs is inherently challenging, as it involves translating the complex three-dimensional anatomy of teeth, which often have multiple roots, into two-dimensional images. Therefore, distinguishing foreground from background, recognising patterns, and appreciating spatial relationships become essential observational skills for dental practitioners. Given the critical role of radiographic imaging in endodontic care and the increasing demand for accurate and efficient radiographic interpretation, enhancing dental students' perceptual skills is essential. Upon graduation, many dental students will be expected to interpret radiographs quickly and confidently to support timely clinical decisions. For instance, accurately determining whether a root canal-treated tooth should receive a definitive restoration or undergo retreatment requires precise observational skills, rapid analysis, and informed clinical judgment. However, the foundational skills of visual analysis

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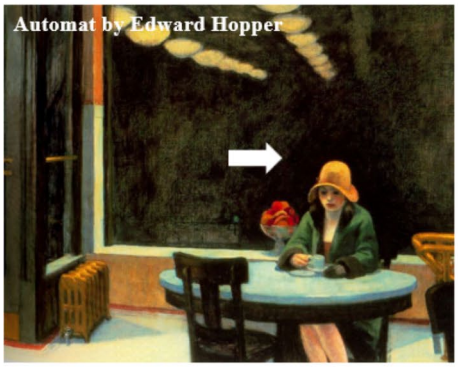
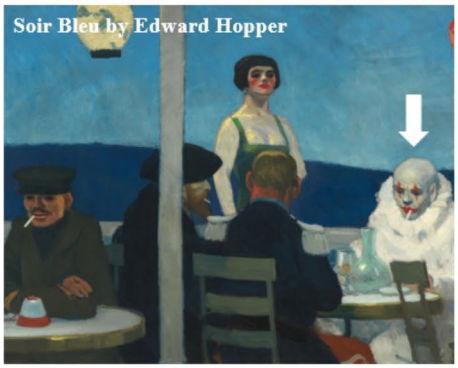
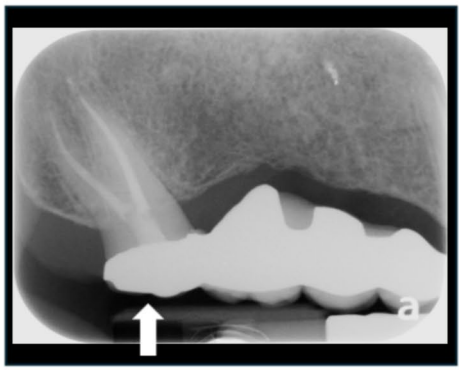
**(a) Subtle contrast; foreground element isolated by tonal shift**

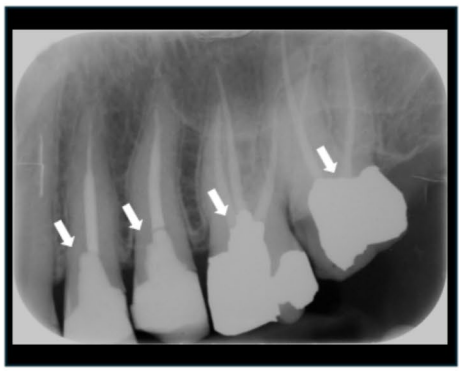



**(b) Unequal distribution of emotional and mechanical weight**

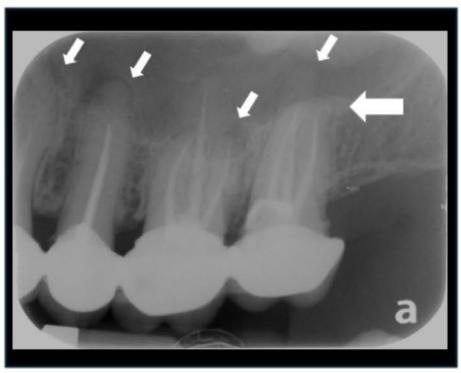



**(c) Critical yet hidden; the invisible foundation**

**(d) Repetitive visual cues suggesting interconnected clinical decisions**

◂**Fig. 1** Comparative illustration of envisioned visual analytical principles linking artwork to radiographic interpretation. **A** Left: The subtle absence of shadow behind the woman creates a contrast against the darker background, isolating and emphasising her presence. Right: Radiograph of an upper first molar showing a similarly subtle yet distinct radiolucent area around the palatal root apex, isolating and emphasising its clinical importance. **B** Left: Figures appear close in space yet emotionally disconnected. The clown, central yet alienated, suggests an imbalance in emotional presence and burden. Right: Radiograph depicting a tooth that, despite optimal root canal obturation, carries an excessive mechanical load previously distributed among multiple teeth. Just as Hopper's isolated figures seek meaning externally, the tooth's prognosis becomes questionable due to external, disproportionate stresses. **C** Left: All focal elements including meat, bread, and poultry depend on fire, yet fire is never directly shown. The painting highlights how an unseen element can be central to maintaining function and order. Right: Radiograph showing suboptimally obturated canals with a carefully sealed access cavity. The strong coronal seal has likely preserved function after 1 year. This example highlights the value of recognising stabilising factors to avoid overtreatment. **D** Left: The lavish foreground contrasts with the quieter background, where a moral message is embedded. Patterns emerge in the repetition of animals on produce baskets. The seated man with a deformed arm draws subtle attention to overlooked details. Right: Radiograph showing suboptimally obturated canals in all visible teeth, each crowned and splinted together. The instinct may be to spare the upper first molar and retreat only the second molar and premolars. However, given the similar treatment style and emerging apical pathology across the arch, retreatment of all affected units may be the safer course. The dilacerated root of the second molar resembles the crooked arm of the seated man, which is an element that might be overlooked without deliberate inspection. This pairing underlines the importance of stepping back to reassess the full visual and clinical pattern before forming a conclusion

and interpretation are rarely taught explicitly within dental curricula. While training in diagnostic imaging introduces students to recognising technical errors and acceptable standards, the act of careful and deliberate looking is often assumed rather than intentionally developed [3]. Research related to errors in diagnostic radiography has shown that visual perception errors account for between 60 and 80% of interpretation mistakes made by clinicians and radiologists [4]. Many medical schools have integrated art-based training into their curricula [5–11], with the earliest documented implementation dating back to 1986 [12]. Among these, several studies have specifically examined the impact of art-based visual training on radiographic observational skills, including two in veterinary medicine [13, 14]; however, none of these studies has addressed dental radiographic interpretation [15–18].

Visual thinking strategies (VTS) offer a constructivist framework for developing visual literacy through guided group discussion of artworks [19]. In VTS sessions, facilitators pose open-ended questions to prompt detailed observation, require support of interpretations with visual evidence, and encourage consideration of multiple viewpoints in a supportive, non-judgmental environment. A recent systematic review concluded that, despite variability in study design and outcomes, the VTS approach consistently appears to enhance crucial clinical competencies through a deeper visual analysis [20]. Nevertheless, the review also highlighted common methodological limitations such as a lack of control groups and non-standardised outcome measures, emphasising the need for more rigorously designed studies to clarify the true benefits of VTS training. Given these insights and the absence of studies specifically exploring art-based visual training for dental students' radiographic interpretation, there is a strong rationale to investigate the use of VTS within this context. Radiographs of root canal obturation were specifically chosen because accurate interpretation of these images has high clinical significance, directly influencing treatment decisions and patient outcomes. Therefore, this study aimed to evaluate whether structured VTS training, using carefully selected artworks, could influence dental students' ability to systematically assess root canal obturation radiographs.

## Methodology

This quasi-experimental mixed-methods study was conducted among 90 third-year dental students enrolled in the Research Practicum module. After ethical approval (Ref AE-2024-0219B), all students were invited by email and via in-class announcement to participate. Participation was voluntary; the first 50 students to consent formed the VTS intervention group (56% female), and the remaining 40 served as controls (55% female). Verbal informed consent was obtained prior to participation, and data collection was anonymised. All participants had completed their preclinical courses in endodontics and diagnostic imaging and were fully trained in performing root canal treatments before enrolment.

The VTS exercise involved small group discussions, with 10 students per group, conducted five times to train a total of 50 students. Each session, lasting 180 min, focused on four paintings carefully selected for their relevance to observational analysis: *The Four Elements: Fire* and *The Well-Stocked Kitchen* by Joachim Beuckelaer, as well as *Soir Bleu* and *Automat* by Edward Hopper. These artworks were chosen because they feature rich visual details, layered compositions, and ambiguous elements that encourage multiple interpretations. The paintings also reflect key principles relevant to radiographic evaluation, such as distinguishing foreground from background, recognising patterns, and assessing spatial relationships.

Figure 1 conceptually illustrates the authors' rationale in selecting specific artworks to train observational skills relevant to radiographic interpretation. This exemplary illustration showcases the alignment of visual training with clinical judgment, the identification of subtle but essential elements

**Table 1** Core VTS questions and supplementary prompts used in each phase

| Phase | Core questions | Supplementary prompts |
|---|---|---|
| Observation | - *What do you see?*<br>- *What makes you say that?*<br>- *What else do you see?* | - *Identify areas of high contrast between light and dark*<br>- *Point out objects in the foreground and background*<br>- *Note any repeating shapes or patterns* |
| Interpretation | - *What do you think this represents?*<br>- *What different perspectives can be considered?* | - *Hypothesise meanings behind colour or composition choices*<br>- *Consider spatial relationships among elements*<br>- *Question any assumptions you may be making* |
| Reflection | - *Does this interpretation hold up under closer examination?*<br>- *How might prior experiences shape your perception?* | - *Reflect on changes in your interpretation after hearing others*<br>- *Assess how reliable each visual cue is under scrutiny*<br>- *Examine how your background influenced your reading* |
| Communication | - *How would you explain your interpretation to someone unfamiliar with the image?*<br>- *How did hearing others influence your reading?* | - *Practice explaining your reasoning step by step*<br>- *Invite peers to challenge or expand upon your interpretation*<br>- *Note how group discussion shaped your conclusions* |

that contribute to overall function, and the association of thematic observations in artwork with interpretation skills used in clinical radiographic analysis.

At the start of each session, students were asked to spend 3 min independently writing their initial thoughts on an index card for each of the four selected paintings. The sessions were facilitated by the lead investigator, who was VTS-certified. Students were guided through the process using VTS questions, supplemented with additional prompts to structure the discussion into four steps (Table 1). This complete sequence of observation, interpretation, reflection, and communication was applied individually to each of the four paintings. The observation phase aimed to identify objective visual findings, with students responding to the questions: "What do you see?", "What makes you say that?", and "What else do you see?" In the interpretation phase, where students drew conclusions about the meaning of the work, they were asked: "What do you think this represents?" and "What different perspectives can be considered?" The reflection phase encouraged students to evaluate their conclusions and question validity through prompts such as: "Does this interpretation hold up under closer examination?" and "How might prior experiences and knowledge shape your perception?" The facilitator encouraged students to articulate observations, justify their interpretations, and consider alternative perspectives. The questions were repeated throughout the session and directed at different students to foster inclusive participation and to encourage deeper engagement with the images. The facilitator maintained neutrality while expressing interest in each response and continuously referred back to the image to keep the group's focus grounded in visual evidence. Once the discussion was concluded and no further comments were offered, students were asked to write a second reflective response on the back of each of their original index cards, with one card corresponding to each painting. All free-text responses (initial and reflective) were transcribed verbatim and reviewed. Using a basic content-analysis approach, similar ideas were grouped into descriptive categories and representative quotations were selected to illustrate each category.

One week after completion of the VTS training, all assessments were conducted at the same institution with the same cohort. The 50 VTS-trained students and the 40 untrained students each viewed 198 periapical radiographs retrieved from the local archive and taken one year after root canal treatment, viewing them individually on a large screen. This sample size was determined by power analysis ($\alpha = 0.05$, $\beta = 0.20$) to ensure adequate sensitivity for detecting differences in agreement between groups. Inclusion criteria included periapical radiographs of multi-rooted teeth taken 10 to 14 months after root canal treatment, with complete visualisation of all root apices and high diagnostic quality without motion blur or distortion.

Each participant had 30 s per image to assess treatment quality using a checklist-based global assessment approach, assigning a score from 0 to 5, with each point reflecting adherence to predefined European Society of Endodontology quality guidelines (ESE) [21], as seen in Table 2. Four 5-min breaks were distributed evenly across the session for both student groups, resulting in a total assessment time of 120 min. Following the student assessments, a panel of four endodontic specialists independently rated the same 198 radiographs under identical timing conditions. After completing their individual scores, the specialists met to resolve any discrepancies and record a single consensus score for each image.

Statistical analyses were performed to evaluate differences and agreement among the three groups. First, an omnibus Friedman rank sum test was conducted to compare the three sets of related scores across cases. Pairwise comparisons between groups were subsequently examined using paired Wilcoxon signed-rank tests with Bonferroni adjustments. To assess agreement with the specialist consensus, absolute differences between each student group's score and the specialist score were computed for each case, and a paired Wilcoxon signed-rank test was used to compare

**Table 2** Obturation quality criteria and scoring rubric

| Criterion | Score |
|---|---|
| 1. Canal filled completely unless post or core space reserved | 1 if yes, 0 if no |
| 2. Filling follows original canal anatomy | 1 if yes, 0 if no |
| 3. No voids within the filling and no gaps between filling and canal wall | 1 if yes, 0 if no |
| 4. No extruded material beyond the estimated apical constriction | 1 if yes, 0 if no |
| 5. Adequate coronal restoration with intraorifice seal | 1 if yes, 0 if no |

Students scored each radiograph by scoring "1" or "0" for each of the five criteria. The total (0–5) constituted the treatment-quality score

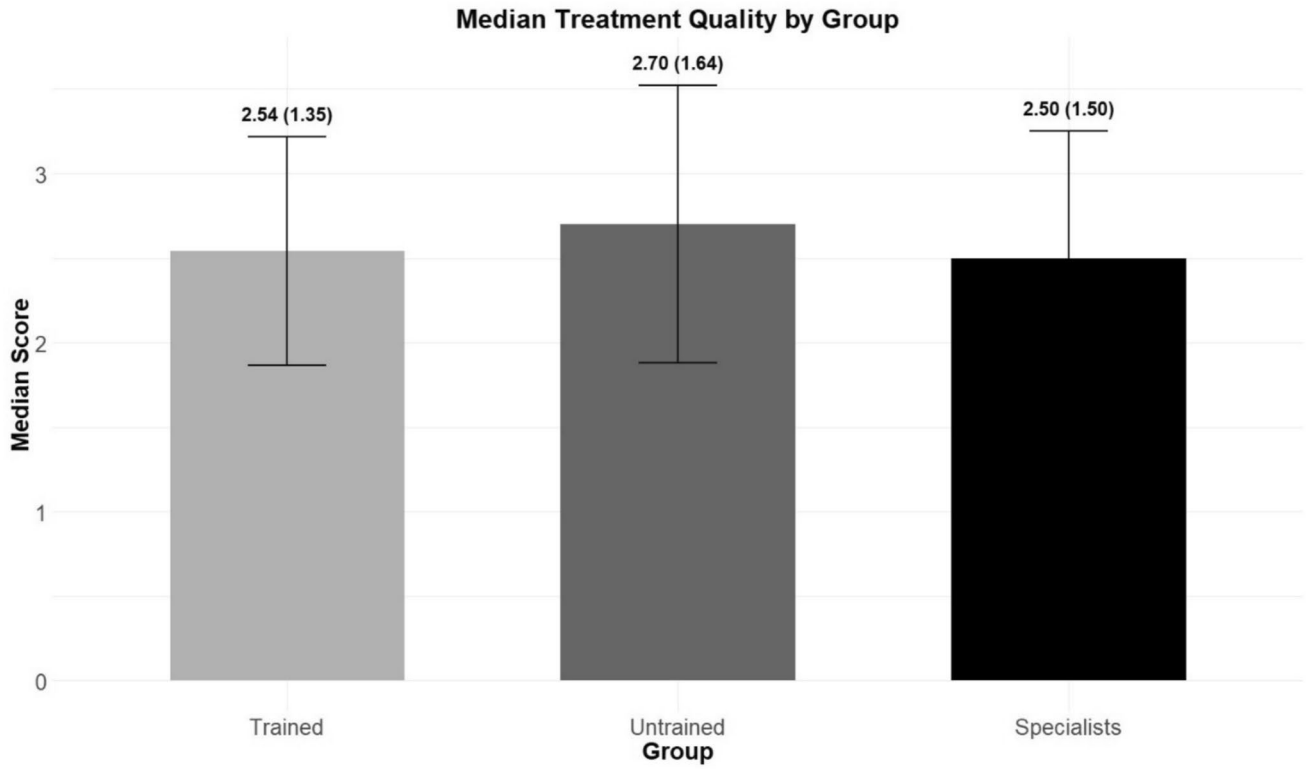



**Fig. 2** Median treatment quality ratings by group. Bar chart displaying the median treatment quality scores, with error bars representing the interquartile range (IQR), for 198 cases as rated by three groups: trained students, untrained students, and specialists. Numeric annotations above each bar indicate the median and IQR for each group

these deviations. In addition, intraclass correlation coefficients (ICCs) were calculated using a two-way consistency model to quantify the agreement between each student group and the specialists. All statistical analyses were conducted in R version 4.4.3 (The R Foundation for Statistical Computing). Data manipulation was handled using *tidyr* and dplyr, while afex and emmeans were used for repeated-measures analyses and post-hoc comparisons. Base R functions were used for omnibus tests and non-parametric pairwise comparisons. Agreement analyses, including ICC computation, were performed using the *irr* package. A line graph was generated with *ggplot2*, applying *geom_line()* to visualise individual case ratings across groups and *geom_smooth()* (loess method) to highlight trends. Statistical significance was set at $\alpha = 0.05$.

## Results

During data screening, three students from each group were excluded due to erroneous ratings outside the defined scale, reducing the final sample sizes to 47 trained students and 37 untrained students. The median (IQR) ratings were 2.54 (1.35) for the trained students, 2.70 (1.64) for the untrained students, and 2.50 (1.5) for the specialists (Fig. 2). Figure 3 displays the smoothed line graph of the ratings for trained,


**Fig. 3** Trends in case ratings across groups. Line graph depicting the individual case ratings for the three groups across all 198 cases. Each trend line is distinguished by its line type (solid for trained students, dashed for untrained students, and dotted for specialists) and smoothed to illustrate the overall pattern of treatment quality ratings over cases. This figure highlights the consistency and variation in ratings across cases for each group

untrained, and specialists across the 198 cases. The specialists maintained a comparatively consistent pattern, while the trained students generally tracked closer to the specialists. In contrast, the untrained students showed greater variability and appear to deviate more frequently from the specialist ratings. The omnibus Friedman test revealed a significant difference among the ratings provided by the three groups across the 198 cases ($X^2 = 20.8$, $p < 0.0001$). Pairwise comparisons using the Wilcoxon signed-rank test showed that the scores of the trained students differed significantly from those of the untrained students ($V = 12{,}894$, $p < 0.0001$). In contrast, there was no significant difference between the trained students and the specialist consensus ($V = 9357$, $p = 0.62$), while the untrained students differed significantly from the specialists ($V = 6871$, $p = 0.001$).

To further assess agreement, absolute differences between each student group's score and the specialist consensus were computed. The paired Wilcoxon test comparing these deviations did not reach significance ($V = 11{,}008$, $p = 0.088$).

Intraclass correlation analyses were also performed. The ICC for the trained students was 0.878 (95% CI, 0.838–0.908; $F(197,197) = 8.17$; $p < 0.0001$), indicating substantial agreement with the specialist ratings. The ICC for the untrained students was 0.799 (95% CI, 0.733–0.848; $F(197,197) = 4.96$; $p < 0.0001$), indicating lower, yet still substantial, agreement.

Several recurring observations emerged regarding how students engaged with VTS during the discussion phase. Most students reported that VTS encouraged them to shift beyond surface-level observations and explore deeper contextual interpretations. The process was described as challenging traditional cognitive habits, requiring students to evaluate compositions with a more open, integrated, and dynamic approach. One student described this cognitive shift explicitly:

> Usually I just look quickly and move on, but this training really forced me to stop and reconsider my first impressions. It was uncomfortable at first, but eventually I saw much more detail.

Several students expressed that the rich use of colour, shadow, and perspective in the selected paintings helped them strengthen their pattern recognition skills. Students also noted that consulting peers during VTS exercises played a crucial role in broadening their interpretative abilities, as hearing alternative perspectives helped them reframe their initial assumptions about the artwork. For example, one student reflected:

> I did not realize how narrow my viewpoint was until I listened to my classmates. Hearing them talk about the same image in a completely different way made me reconsider how I approach looking at anything.

In particular, the food-related symbolism in Beuckelaer's paintings prompted students to differentiate between literal representation and deeper metaphorical meaning. Many initially described the artwork in strictly factual terms, noting the presence of food, market settings, and human activity, while others moved beyond description and considered the socio-economic and cultural implications of the imagery. For example, one student initially wrote:

> There is a variety of meats and fish laid out, some prepared and some fresh. The people in the background are talking, maybe about food or trade.

While this observation is factually accurate, it remains descriptive rather than interpretive. However, after engaging in the VTS discussion, the same student expanded on their initial thoughts:

> The abundance of food might not just be about trade, but about wealth or social class. Maybe it's showing excess, or how food is used to represent power. The background figures look like they're engaged in something other than just shopping, which makes me wonder if the painting is making a statement about daily life versus survival.

Another student noted similarly:

> At first, I only saw the obvious: a market with food. After discussing with my peers, I started seeing a bigger picture about society, trade, and inequality. It surprised me that I missed these points initially.

Similarly, students analysing Hopper's paintings often began with straightforward visual observations before advancing to more subtle readings of spatial arrangement and detail. Initial responses to *Soir Bleu* were frequently centred on its literal elements, such as:

> There are people sitting together, but they do not seem to be interacting. The clown figure is very striking, and the colours are muted.

Following the VTS discussion, many students re-evaluated their observations in a more abstract and psychological way, with responses such as:

> The painting feels lonely even though there are people in it. The clown, instead of looking joyful, feels out of place, which makes me think about isolation or hidden emotions.

A similar pattern emerged with *Automat*, where students initially focused on the lighting, setting, and posture of the figure, but after engaging in discussion, they began to hypothesise about the subject's emotional state and broader themes of solitude or detachment:

> The lighting is harsh, but the woman seems completely absorbed in her own world. It makes me wonder if the painting is about being disconnected from others, even in a public place. This exercise has pushed me outside my usual thought patterns.

Another participant expressed a comparable insight:

> Initially, I thought the painting was straightforward 'a woman alone'. After the group discussion, I realized it might represent more about loneliness or isolation. It taught me to always look for layers of meaning.

Across the dataset, students who initially described artwork in rigid, observational terms often transitioned into more complex, layered interpretations after engaging in the VTS discussion process. As one student summed up their experience:

> This exercise taught me to slow down and not jump to conclusions. It is easy to miss important things when you rush, and now I feel more aware of the need to be thorough and patient in observing details.

## Discussion

This study builds upon previous work in medical education by demonstrating that VTS training can improve radiographic observational skills among dental students [13–17]. To our knowledge, this represents the first investigation of its kind within the context of dental education. Our results indicated that VTS-trained students assessed radiographic images significantly closer to specialist evaluations compared to their untrained peers, suggesting that structured visual training enhances dental students' ability to systematically interpret radiographs. The necessity of explicitly training observational skills is well documented in medical education [13, 15–18], and our findings demonstrate that these competencies can similarly be developed in dental students through brief art-based interventions. This aligns with prior studies that repeatedly confirm improvements in visual diagnostic abilities after engaging with art-based visual training [9, 14].

These outcomes align with prior reports of VTS benefits in medical education and suggest that structured visual training may be applicable to other image-based diagnostic tasks [20]. Previous studies noted that even when the quantitative count of observations did not increase markedly, students

consistently reported greater awareness and mindfulness in observing clinical details [10]. Our participants echoed this sentiment, describing in their feedback a newfound attentiveness to subtle radiographic features and a more deliberate, systematic approach to image interpretation.

Our results also indicated that VTS-trained students identified critical details, such as obturation voids, discrepancies in fill length, and subtle periapical radiolucencies, more consistently with specialist evaluations. This improvement aligns with evidence from previous studies indicating that even brief art-based training significantly enhances learners' visual diagnostic accuracy and their ability to localise radiographic abnormalities [13–15]. Such diagnostic precision is clinically crucial; misinterpretation of radiographs can lead to overlooking critical issues like poor seals or missed canals, while enhanced observational accuracy helps ensure these problems are identified promptly and addressed appropriately. By fostering systematic observation habits, such as thoroughly scanning the entire image and corroborating interpretations with visual evidence, VTS training directly supports improved clinical decision-making, echoing the broader improvements in visual literacy and clinical reasoning highlighted in the literature [20].

It is noteworthy that these improvements were observed in a quasi-experimental design following a brief training intervention, underscoring the educational potency of VTS. Previous studies described similar goals, aiming to encourage residents to pay closer attention to image details, clearly articulate observations, and coherently integrate these into the diagnostic narrative [17]. Our findings offer empirical support for these educational aims, demonstrating that VTS-trained dental students identified critical radiographic features more consistently and integrated these observations into more cohesive interpretations aligned with specialist evaluations. In contrast to earlier studies that measured observation quantity without detecting significant improvements [10], our study focused specifically on the accuracy and interpretative quality of observations, revealing notable gains. This distinction suggests that VTS particularly enhances higher-order visual diagnostic skills such as pattern recognition, inference, and interpretive coherence, rather than merely increasing the number of observations. This aligns with evidence from medical education, where art-based training improved students' diagnostic reasoning and interpretive accuracy rather than simply enhancing their capacity to enumerate visual details [9]. Our results extend this finding, establishing its relevance within the dental domain.

Arts-based training has previously been shown to enhance medical students' ability to recognise multiple perspectives, identify underlying narratives in their observations, and cultivate empathy through group discussion [22]. Our findings resonate closely with these outcomes; students frequently described how the VTS experience allowed them to appreciate that a single image could yield numerous valid interpretations, thereby fostering deeper, more meaningful analyses. Qualitative feedback further highlighted improved critical thinking skills, with participants describing how VTS discussions compelled them to move beyond habitual cognitive patterns and to approach visual analysis more openly, imaginatively, and integratively, much as was reported in a recent veterinary study [14].

Students noted that group dialogues during VTS created a supportive environment for exploring uncertainty. The non-judgmental nature of the VTS method, in which every contribution is paraphrased and positively reinforced by the facilitator, encouraged students to comfortably share tentative or creative ideas without fear of making mistakes. This aspect is particularly valuable in clinical training, as novice dental students often hesitate to voice uncertain interpretations of radiographs. Through VTS discussions, students learned that considering uncertain or unlikely hypotheses can lead to deeper insight and discovery. Similar educational climates have been described in other health professions, where a safe environment empowered learners to think and perceive differently, ultimately enriching their understanding [18]. Indeed, our sessions showed that students' willingness to openly explore uncertainty led to more nuanced discussions, characterised by frequent "what if" questions and a collective examination of ideas. This aligns with recent findings highlighting VTS as fostering increased tolerance for ambiguity and enabling students to embrace uncertainty as a tool for deeper inquiry [11]. In practice, this means our students are now less likely to ignore confusing radiographic evidence; instead, they may recognise it as a cue to look closer or seek additional input.

The positive outcomes of this study carry important implications for dental education. Incorporating VTS or similar arts-based observation exercises into dental curricula could address a recognised gap in explicitly training observational skills [3, 10]. In dentistry, as in medicine, keen observation is crucial, whether interpreting radiographs, examining oral lesions, or evaluating the aesthetics of restorations. Yet, perceptual skills are frequently assumed rather than intentionally cultivated. Our results demonstrate that brief, targeted interventions using art can effectively prepare students to observe systematically before they apply these skills clinically. Similar initiatives, such as Harvard's "Training the Eye" course, have successfully employed art-based observation to enhance physical diagnostic skills in medical students [20]. Analogously, integrating such methods into dental education could systematically enhance students' visual diagnostic competencies. The measurable increase in agreement between trained students and specialists when evaluating root canal obturations may therefore suggest

potential for broader gains in visual literacy across other dental imaging tasks.

Introducing VTS into dental education could also help humanise the learning experience [23, 24], reminding students that dentistry involves art as well as science. Additionally, our findings suggest promising opportunities for interprofessional education. Given that VTS has now been successfully implemented across medicine, veterinary medicine, nursing, and dentistry, it offers common ground for cross-disciplinary collaboration. Joint VTS sessions among dental, medical, and nursing students, focusing on art or clinical imagery, could enhance communication skills, foster team-based observational practice, and simulate real-world interprofessional interactions. Previous research highlighted how art-based observation training encouraged learners to perceive patients holistically rather than as isolated clinical issues [3]. Such a collaborative approach could further enrich students' understanding by integrating diverse professional perspectives, preparing them to effectively engage in interdisciplinary clinical teams. Ultimately, incorporating VTS into dental education highlights the potential of innovative teaching methods, demonstrating that looking beyond traditional approaches can meaningfully enhance clinical observation and diagnostic skills.

Although dentists rightly take pride in the wealth of critical information that radiographs provide, we must also remain mindful that these images can never fully capture the complexity and humanity of the patients they represent. Interpreting radiographs is fundamentally a representational dental art, and representations inevitably simplify and abstract reality. As Gunderman and Idahosa (2017) remind us, "Behind every static radiologic image is a living, breathing human being with a still-unfolding life story" [16].

Several limitations of this study must be considered. First, although the study employed a quasi-experimental design with a non-trained control group, randomisation of participants was not performed, potentially introducing selection bias. Moreover, academic performance data were not collected, so pre-existing differences in clinical ability or academic achievement between the trained and untrained groups cannot be ruled out. Additionally, students who volunteered for the VTS training may have inherently greater motivation or openness to visual training methods, which could have influenced their outcomes. Furthermore, the study used radiographs retrieved from the local archive of a single dental hospital; and thus, the generalisability of findings to other institutions or clinical settings remains uncertain. The radiographs were selected by a panel of specialists, but inherent subjectivity in selection criteria might still influence representativeness. While the evaluation session provided a standardised timeframe of 30 s per radiograph, this artificial constraint may not fully reflect real-world clinical decision-making scenarios. In addition, all images were presented in the same predetermined order and a modest decline in scores toward the end of the session suggests that cognitive fatigue may have influenced later ratings. Although the ICC results indicated substantial agreement with specialist ratings, the short interval between VTS training and radiographic assessment does not clarify whether these observational skills are retained over time.

The findings of this work open several promising research avenues. A matched-cohort or crossover study could compare VTS with alternative visual training methods within the same student cohort, helping control for individual differences. Longitudinal follow-ups at 3, 6, and 12 months would clarify skill retention and real-world diagnostic impact. Incorporating objective measures such as eye-tracking to map visual search patterns or decision-time analyses could reveal how VTS alters perceptual strategies. Finally, qualitative interviews with students and faculty would explore how enhanced observation skills translate into clinical confidence and patient care outcomes.

## Conclusion

This study provides initial evidence supporting the use of VTS in dental education to improve students' radiographic observational and interpretive skills. Our results indicate that dental students trained with VTS achieve greater agreement with specialist evaluations, suggesting enhanced accuracy in radiographic assessments of root canal obturation. The integration of structured visual training into dental curricula may therefore represent a valuable educational innovation, fostering improved diagnostic skills in endodontic radiology.

**Data Availability** The data that support the findings of this study are available from the author upon reasonable request.

## Declarations

**Ethics Approval** The study is approved by the Institutional Review Board (ERIC) (Ref: AE-2024-0219B).

**Consent to Participate** Subjects provided consent to participate in the study.

**Conflict of interest** The authors declare no competing interests.

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