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Abstract

Purpose: This study explored dental students' perceptions of arranging denture teeth in complete denture cases, the impact of digital support on learning strategies, and differences in their experiences based on whether they had access to digital support.

Methods: In this qualitative case study, a total of 14 students were randomly assigned to either the digital or non-digital support group. The digital group performed digital teeth arrangements, followed by manual tooth arrangements, with access to a 3D viewer, 3D-printed model, and instructor feedback. The non-digital group received only instructor feedback. While the sample size was limited, it is consistent with the purpose and depth of exploratory qualitative case study methodology.

Results: Students reported that arranging teeth for patient-specific dentures provided authentic learning experiences, deepening their understanding of laboratory and clinical processes while enhancing motivation and responsibility. The non-digital group encountered difficulties in independently applying theoretical concepts and found peer references of limited usefulness, leading to reliance on supervisor feedback and the search for alternative visual resources. In contrast, digital supports enhanced learning by reinforcing prior knowledge, reducing anxiety, improving three-dimensional understanding, and facilitating reflective practice. Effective denture teeth arrangement with digital support relied on sufficient time, instructor guidance, and structured feedback.

Conclusions: Denture teeth arrangement enhanced students' understanding and provided a practical learning experience, while the complexity of the task imposed emotional burdens. Digital support increased students' confidence and promoted three-dimensional understanding and self-reflection. Strategies have been proposed to enhance the educational effectiveness of combining denture teeth arrangement with digital support.

Keywords: Complete denture, Dental education, Teeth arrangement, 3D printing, Digital technology

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1. Introduction

Teeth arrangement is a fundamental step in the fabrication of removable dental prostheses, in which artificial teeth are positioned on a denture base to restore oral function and appearance for edentulous patients. This complex process requires an understanding of dental function and esthetics, as well as consideration of individual patient needs and preferences [1,2]. Although most dentists delegate the teeth arrangement procedure to dental technicians, some dental schools train dental students to perform teeth arrangements themselves in a clinical education context. During the teeth arrangement process, students made multiple revisions based on supervisor feedback and worked independently over several days to improve their outcomes.

The growing clinical adoption of digital complete dentures and increasing commercial availability underscore the need to integrate digital denture training into dental curricula [3]. A 2023 nationwide survey revealed that 88.06 % of U.S. predoctoral programs and 95.65 % of postdoctoral prosthodontic programs had already incorporated digital complete denture workflows into one or more stages of their curriculum [4]. Digital denture education spans preclinical didactic, laboratory, and clinical components [5]. For instance, 3D visualization tools have been used in preclinical instruction to teach denture design principles, offering students cost-effective and mobile-accessible learning via smartphones [6]. In hybrid preclinical programs, students engage in digital tooth arrangement, trial denture try-ins, and both virtual and physical adjustments [3]. These experiences provide a foundation for clinical integration, where students apply digital workflows directly in patient care [3].

Despite the shift toward digital complete dentures, conventional educational methods continue to play a vital role. Given the limited time available for dental education, exploring effective approaches that integrate conventional and digital methods in clinical training is crucial. Such integration enables students to gain hands-on experience with digital technologies while enhancing their clinical competence in standard treatments. In this context, this study aimed to explore dental students' perceptions of the necessity of independently aligning denture teeth in a clinical education setting, as well as the impact of digital tools on their learning strategies. The research questions were:

1. How do students perceive the experience of arranging denture teeth in patient cases?
2. What impact does digital support have on the learning strategies of dental students during denture teeth alignment?

2. Methods

Figure 1 illustrates the overall research flow of the study. This study was approved by an Institutional Review Board (2-2022-0059), and informed consent was obtained from the participating students after they were informed of the purpose, background, safety measures, confidentiality, and compliance with the ethical standards of the study.

2.1. Characteristics of exploratory case study

A case study is an empirical method used to investigate a phenomenon within its real-life context, particularly when the boundaries between the phenomenon and its context are unclear [7]. It

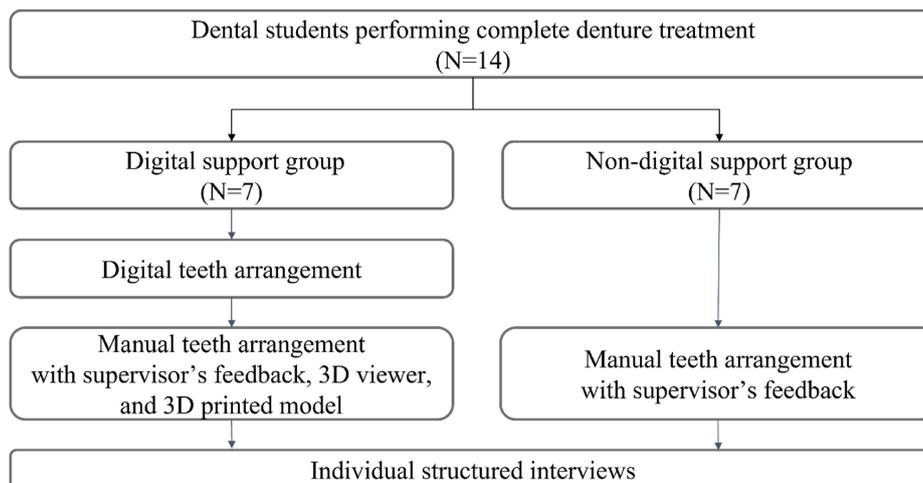


Fig. 1. Overall flow of this study.

closely reflects real-life situations and allows direct exploration of perspectives related to unfolding phenomena [8]. Case studies are particularly suited for research involving “how” and “why” questions [9]. By examining cases in depth, unexpected information may emerge, making them valuable for developing hypotheses that inform future research [10]. Case studies can be categorized as exploratory or descriptive based on their purpose [11]. Exploratory case studies investigate interventions that have not been previously evaluated or for which outcomes are not well-established.

2.2. Research participants

Convenience and purposive sampling were conducted to recruit participants. The participants were limited to third- or fourth-year dental students engaged in complete denture treatment for patients and preparing to arrange the resin teeth of the denture. All participants had received training in complete denture fabrication through conventional methods, including lectures and preclinical laboratory exercises. However, they had no prior experience with digital denture procedures or software. Students were randomly assigned to non-digital and digital support using block randomization to prevent imbalances in participant numbers during fixed allocation. The block size was fixed at two.

3. Digital support group

In this study, “digital support” was operationally defined as the provision of a digital teeth arrangement experience using CAD software, combined

with optional learning resources such as a 3D viewer application and 3D-printed denture replicas. Figure 2 presents an overview of the digital workflow and accompanying resources provided to students in the digital support group. In the digital support group, maxillary and mandibular models with wax rims were scanned using a tabletop scanner (T500, Medit, Seoul, Korea). Students performed digital teeth arrangements with CAD software (3Shape Dental System software, 3Shape A/S, Copenhagen, Denmark), selecting digital teeth matching the manually aligned teeth. They specified reference points (e.g., incisive papilla or retro-molar pad), and the software generated alignment results. Students refined the teeth positions, finalized the arrangement, and received instructor feedback. The entire process took 60–80 min, with 20 min for students to independently adjust the suggested arrangement. After completing the digital teeth arrangements, students received two types of support: a 3D-printed denture replica within two to three days and immediate access to digital images via a 3D viewer app. These learning resources were optional, and students decided how and when to use them based on their own judgment and preferred workflow during teeth arrangement.

3.1. Non-digital support group

In the non-digital support group, students began arranging teeth after the instructor confirmed the condition of the mounted models. Without the aid of digital tools, they worked independently, approaching the task based on their own understanding and previously learned techniques.

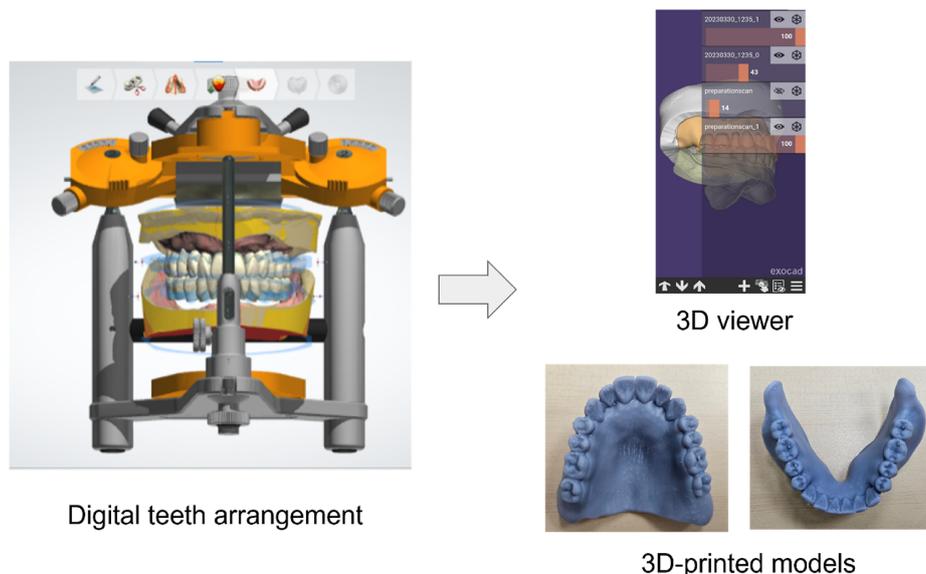


Fig. 2. Digital teeth alignment process and resources provided to the digital support group.

3.2. Instructor's feedback

In this study, a prosthodontics instructor provided feedback on teeth arrangement in three stages: a) anterior teeth, b) mandibular posterior teeth, and c) maxillary posterior teeth. Feedback was unlimited and provided until the criteria for appropriate arrangement were met. Verbal feedback was supplemented with a feedback record, documenting corrections through drawings or notes, organized cumulatively by date.

3.3. Data collection through performance record sheets and interviews

In this study, students used performance record sheets to document the date, stages, and start and end times of their teeth arrangement rounds, with breaks longer than 10 min marking the start of a new round. Individual interviews were conducted by two researchers using structured questionnaires (Table 1), encouraging students to express their opinions freely. Participants also brought their performance record sheets, 3D-printed models, and 3D viewers to provide detailed explanations of their experiences.

3.4. Data analysis

This study employed the six-phase thematic analysis method outlined by Braun and Clarke [12].

The researchers familiarized themselves with the data by repeatedly reading transcripts and generating initial codes that captured meaningful features. Similar codes were then organized into potential themes, which were reviewed for internal consistency and distinctiveness across the dataset [13]. Finally, clear definitions and names were assigned to each theme, and an analytic narrative was developed to address the research questions. Given the qualitative case study design and small sample size, only descriptive statistics were reported to contextualize the time-based data, and inferential statistical tests were not conducted.

3.5. Establishing reliability and validity

Four types of triangulations are recognized for enhancing validity in qualitative research: data triangulation (correlating people, time, and space), investigator triangulation (involving multiple researchers), theory triangulation (applying various theories), and methodological triangulation (employing diverse data collection methods) [14]. In this study, for data triangulation, the researcher (B Lee) observed students' behaviors and provided feedback during teeth arrangement. Investigator triangulation was achieved through an instructor specializing in complete denture education (JE Kim) evaluating the accuracy of data interpretations. For theory triangulation, education professors (EB Yang and SY Kim) analyzed the data through multiple

Table 1. Interview questions for the denture teeth alignment experience.

Category	Questions	Target group	
		Digital support group	Non-Digital support group
Perception of teeth alignment experience	Do you believe it is educationally necessary to independently arrange denture teeth in actual patient cases? Why?	O	O
Performance strategy	What strategies did you use during the teeth alignment process?	O	O
Difficulties experienced	What challenges did you encounter during the process of aligning the patient's teeth?	O	O
Suggestions	What resources or strategies do you think are needed to support learning through teeth alignment experience in denture education?	O	O
Perception of the CAD process	Did you find the process of using CAD software for producing a denture easy or difficult? Why? Was the experience of digital teeth alignment helpful in understanding related concepts? Why?	O	–
Perception of the 3D image viewer	How often and in what ways did you use the 3D image viewer during teeth alignment? Do you believe the 3D image viewer is useful for teeth alignment? Why?	O	–
Perception of the 3D-printed model	How often and in what ways did you use the 3D-printed models during teeth alignment? Do you believe 3D-printed models are useful for teeth alignment? Why?	O	–

educational perspectives. Methodological triangulation incorporated performance records and interview data.

4. Results

4.1. Research participants and their performance record of teeth arrangement

A total of 14 students participated in this study, with seven being randomly assigned to the non-digital and digital support groups. Table 2 presents the performance duration and frequency of instructor feedback for each participant, while Fig. 3 illustrates the group-level averages. The average total time spent was 21.59 h for the non-digital group and 18.74 h for the digital group. The average frequency of instructor feedback was 6.86 times in the non-digital group and 5.57 times in the digital group.

4.2. Experiencing authentic learning through patient-specific tooth arrangement

4.2.1. Enhanced laboratory and clinical understanding through hands-on experience

Students acknowledged that while denture teeth alignment could be outsourced to a dental laboratory, performing the tasks themselves provided them with a deeper understanding of “the overall dental laboratory and clinical process” (DS2). They noted that forming a bilateral balanced occlusion in patient cases helped them better grasp related concepts. When outsourced, students would “simply check the results” (NS3), but arranging teeth independently prompted them to review textbooks,

enhancing their understanding. As one student explained, “My understanding increased as I applied what I knew in theory” (DS1).

4.2.2. Authentic learning through patient-specific conditions

Clinically, achieving a patient's natural aesthetics required adjustments tailored to factors such as gender, age, or natural irregularities. One student shared, “I was so focused on the standard measurements, but clinically, modifications considering the patient's age were necessary” (DS2). Another noted, “Before the esthetic try-in, I adjusted the anterior teeth slightly unevenly to reflect natural aesthetics, following my clinical advisor's advice” (NS5). These examples highlight how authentic learning through patient-specific conditions occurs, as students move beyond standard measurements and gain experience in individualizing esthetic decisions for each patient.

4.2.3. Procedural complexity and emotional responses

Teeth arrangement posed unique challenges compared to other dental procedures, due to the need for continuous modifications throughout the process. One student highlighted the complexity, saying, “It takes a lot of time to correct the teeth arrangement; this happens because even if only one anterior tooth has to be pushed back, all the posterior teeth have to be pushed back one by one” (NS3). The small size of the denture teeth increased the difficulty. Another student explained, “The teeth kept slipping out of my hands and melting the wax, which made the process more frustrating” (DS4). As a result, students experienced varying levels of stress, depending on their interest and aptitude in

Table 2. Performance duration and feedback frequency by participant.

Participants	Performance Duration			Frequency of Instructor Feedback (n)
	Total time taken (h)	Number of recorded sessions (n)	Average duration of a session (h/time)	
Non-digital support (NS) group				
NS1	25.7	18	1.4	13
NS2	16.9	12	1.3	5
NS3	21.2	9	2.4	6
NS4	20.0	6	3.3	6
NS5	26.9	24	1.1	4
NS6	26.2	13	2	6
NS7	14.2	20	0.7	8
Digital support (DS) group				
DS1	12.5	10	1.3	7
DS2	17	8	1.9	5
DS3	16.7	13	1.3	6
DS4	27	12	2.3	5
DS5	9.8	7	1.4	4
DS6	17.7	17	1	4
DS7	31.1	18	1.7	8

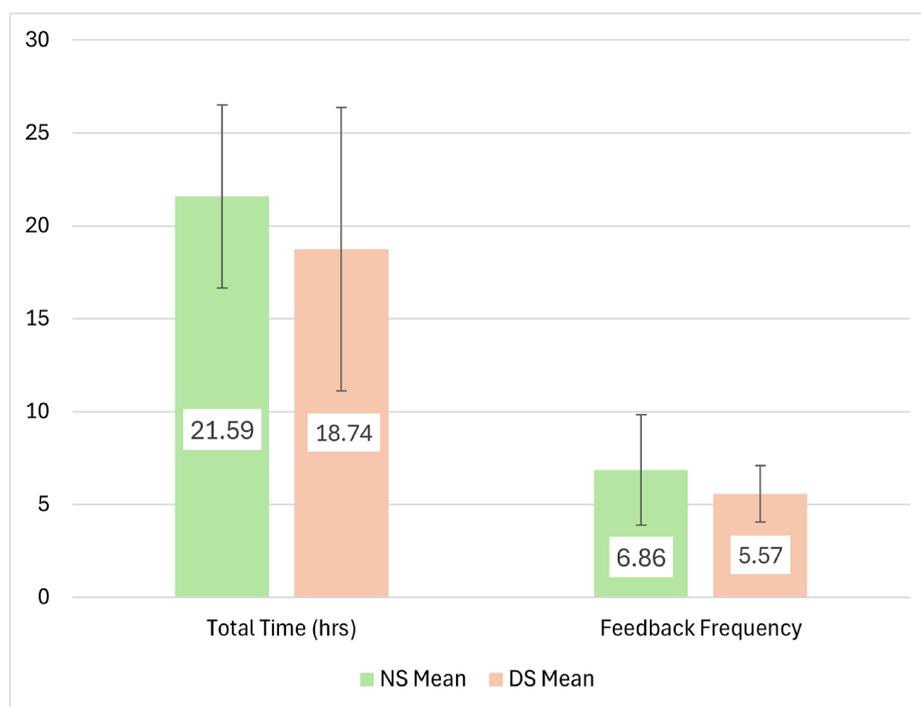


Fig. 3. Total time spent and frequency of instructor feedback by group.

laboratory work. One student shared that “*it was difficult, but since I enjoy dental work, it wasn't too hard*” (NS3), whereas another noted that “*some students don't enjoy lab work and find it stressful*” (NS6).

4.2.4. Motivational drive and psychological pressure

Learning from patient cases increased students' motivation and responsibility, with one stating, “*I feel more motivated because I have a greater sense of responsibility*” (DS5). This accountability pushed them to prioritize quality, as another noted, “*It's not just about passing the instructor's approval, but doing it well*” (DS3). However, there was a sense of pressure to perform well in clinical practice because, as one student expressed, “*In a patient case, it directly impacts the patient, making the pressure substantially greater*” (DS4). Time constraints further heightened the stress, as one student noted, “*When arranging teeth, I think there was more time pressure on patient cases than in model-based practice because patient care should not be delayed*” (NS3).

4.3. Instructor-dependent learning amid resource constraints

4.3.1. Difficulty in independently applying theoretical concepts

The primary references used by students in the non-digital support group were “*guidebooks and textbooks*” (NS1). The non-digital group struggled to

identify anatomical landmarks and apply concepts like Pound's triangle. One student noted, “*Pound's triangle is in the book, but I wasn't sure of its location or whether the lingual cusp referred to the tip or other parts*” (NS2).

4.3.2. Seeking alternative visual resources

In an effort to compensate for the lack of clear visual guidance and their difficulty in applying theoretical knowledge, students turned to online case photos and typodont comparisons. One said, “*I searched online for cases*” (NS7), and another noted, “*I compared my typodont to adjust my work*” (NS6). Students in the non-digital group emphasized the need for visual resources. One said, “*A photo of a well-aligned arrangement might have made the process more comprehensible*” (NS7). Another highlighted the importance of step-by-step resources, saying, “*It would help to have a record base, wax rim, and a model with teeth arranged*” (NS2).

4.3.3. Limited peer references and reliance on supervisor feedback

The non-digital support group found collaboration with peers helpful, though its usefulness was limited due to the diversity of clinical cases. One student said, “*I took pictures of my colleagues' completed works, but the arch shape differed by case, so it was hard to refer to others*” (NS3). Another noted, “*Each patient's form was so different that I wasn't sure if*

examples applied to my patient” (NS2). Despite these challenges, repeated feedback from the instructor helped students gradually internalize alignment standards, which improved their confidence and skills. One student reflected that, as they received more feedback, “things seemed to improve after that” (NS7) as they received more feedback.

4.4. Advancing understanding and reflection with digital and 3D resources

4.4.1. Reinforcing prior learning and confidence via digital tooth arrangement

By engaging in digital teeth arrangement, students reduced anxiety and gained confidence in performing teeth alignment. One student noted, “It was a great help in reminding me of what I had learned in the past” (DS5), while another shared, “I was afraid to try teeth alignment in patient cases, but digital teeth arrangement helped me feel confident that I could perform in the same manner.” (DS2).

4.4.2. Deepened three-dimensional understanding with 3D viewer support

Students primarily used the 3D viewer to assess and refine teeth arrangement in relation to intraoral structures. One noted, “I compared the 3D image file and realized the teeth should be arranged more lingually” (DS7), showing how the viewer improved understanding and application. It was especially useful for visualizing intraoral structures and the relationship between teeth arrangements and the wax rim. A student explained, “I could check the relationship by adjusting the density of the wax-rim image” (DS7). While a phone's small screen was less effective for this purpose (DS2), a tablet proved more helpful (DS7).

4.4.3. Reflective learning and self-assessment through 3D-printed models

Students found the 3D-printed model to be a practical and intuitive reference, enabling direct comparison with their own work. One student noted that it “clearly showed the arrangement and helped me compare it with mine” (DS3). This student found the physical model easier to interpret than the digital viewer, explaining that “the 3D viewer wasn't as helpful—it felt different from seeing it in person” (DS3).

Students highlighted the complementary roles of guidebooks and 3D-printed models. While guidebooks provided basic guidelines, their limited detail often led students to use 3D-printed models for additional support. One student explained, “The practice book wasn't detailed enough, so I often referred

to the 3D-printed model” (DS4). Rather than replicating the models, students used them to verify the angulations and positions of teeth while considering necessary modifications, with one stating, “The 3D-printed model didn't fully match the standards, but it helped me think about how to modify the arrangement” (DS2).

4.5. Strategies for effective denture teeth arrangement with digital support

4.5.1. Adequate time allocation for digital tooth arrangement

Students in the digital support group found digital teeth alignment helpful, even though it was perceived by students to take more time when using these digital tools. One student noted, “Even though it takes time, I think achieving a higher level of precision in digital teeth arrangement is better” (DS3). Another highlighted its efficiency, saying, “Digital teeth alignment and the resulting 3D-printed model are effective in reducing the time required for alignment, and it's worth investing that time” (DS6). However, students also acknowledged that excessive time investment could impact motivation.

4.5.2. Close instructor guidance during digital practices

Students expressed concerns about using the CAD program independently due to a lack of experience. One shared, “It was difficult at first because there were many teeth to align, but it became easier with practice” (DS4). Another noted, “Without the instructor's guidance, it would have been challenging, and the results might have turned out awkward” (DS5). These reflections highlight the need for guidance and practice to build confidence with the software.

4.5.3. Linking practical work with theoretical learning

Students found the instructor's explanations and feedback essential for performing digital teeth arrangement. One student shared, “I learned a lot from the instructor's tips and feedback while showing the screen. I don't think students can learn these things just by trying” (DS7). They also stressed the importance of theoretical preparation, with one saying, “It would be good to study before doing digital teeth alignment” (DS5). These reflections underscore the importance of connecting theoretical study with practical digital exercises.

4.5.4. Structured written feedback

Students emphasized the importance of written feedback from instructors in enhancing their

retention and understanding of the complex concepts involved in teeth arrangements. One student noted, “*I understand feedback in the moment, but I often forget it later. Having it written down allows me to review and reinforce my understanding*” (NS7). These records further strengthened communication between students and instructors. One student remarked, “*Having written feedback makes it easier for me to go over past issues with my instructor and show that I’ve fixed them.*” (NS3).

Students emphasized the benefits of structured guidelines, such as checklists, to enhance their understanding of teeth arrangement principles. One student suggested, “*It’s a good idea to first make sure the main principles are being followed and then give feedback that’s specific to the patient.*” (DS4). Another highlighted the value of step-by-step guidance, saying, “*A checklist of what instructors consider important clinically would be beneficial*” (NS5).

5. Discussion

This study explored dental students’ experiences with independently arranging denture teeth in patient cases, focusing on how digital support influenced their learning strategies. By comparing students with and without digital support, this study examined how these tools impacted their learning approaches.

In examining dental students’ perceptions of teeth arrangement in clinical education, the concept of task value from educational psychology provides a useful framework. Task value includes four elements: attainment value, intrinsic value, utility value, and cost [15,16]. Attainment value relates to the task’s significance in achieving personal goals, whereas intrinsic value reflects interest and enjoyment. Utility value pertains to a task’s relevance to short- or long-term goals, and cost includes time and emotional effort. Students recognized the utility value in understanding teeth arrangement, but intrinsic value varied based on individual aptitude and interest. Costs included time pressures, emotional stress, and anxiety over corrections. Notably, attainment value was less evident, possibly because teeth arrangement is not always seen as a core responsibility of dentists. Understanding these perceptions highlights the importance of emphasizing utility value, reducing costs, and supporting individual differences in intrinsic value to enhance motivation and learning.

Both the non-digital and digital support groups faced challenges related to manual skills and clinical modifications. Manual skills can sometimes hinder learning through constructionism, so if

acquiring technical skills is not the primary educational goal, interventions like tailored coaching may be needed for students with below-average performance. Challenges related to clinical modifications refer to the adjustments required when applying general prosthodontic principles to individual patient cases—due to differences in anatomical structures, functional demands, or esthetic preferences. Such challenges should be considered through the lens of learning transfer, which involves applying prior knowledge and experience to new and diverse clinical contexts. According to major theories of transfer, sufficient abstraction is required for transfer to occur, with abstraction understood as the process of decontextualization [17–19]. Additionally, transfer occurs when the representations constructed by the learner in the initial situation are identical, overlapping, or can be related through mapping [19–24]. Therefore, considering the clinical diversity inherent in the context of clinical education, it is important to develop students’ understanding of generally applicable ideas and make case-specific considerations necessary to empower them to transfer learning from one case to another.

The students’ perception that teeth arrangement enhanced their learning aligns with constructionism, which emphasizes learning through physical creation, or “learning by making.” [25] Unlike constructivism, which emphasizes cognitive processes with minimal guidance, constructionism focuses on structured instruction and tangible product creation, promoting meaningful, student-centered learning through continuous reflection and correction [25–28]. By digitally arranging teeth, students applied prior knowledge while reducing anxiety regarding manual alignment. 3D viewers and 3D-printed models acted as tangible outputs, linking abstract knowledge to physical artifacts and helping students better interpret feedback. Compared to photos, standard models, and social interactions in the non-digital group, digital tools provided more direct guidance, highlighting the importance of integrating these tools into dental education to enhance understanding, reduce anxiety, and improve learning.

Based on students’ reflections, it appears that enhancing prior learning and allocating more time for self-directed digital teeth arrangement may further support their learning experience. In light of the principle of constructionism discussed earlier, the digital teeth arrangement process itself is not a preparation for performance but rather, a process of “learning by making.” Therefore, providing sufficient self-directed learning opportunities is

important for student learning. However, further research is necessary to determine which approach—digital teeth arrangement or manual alignment—is more effective for learning within the framework of constructionism and to better understand how students learn in each scenario.

This study aimed to provide exploratory insights into students' learning strategies during denture teeth arrangement in clinical education. The findings were interpreted through the lens of educational theories, including task value and constructionism. A key limitation of this study is its small sample size, which limits the generalizability of the findings. While this is an inherent constraint of the qualitative case study approach, it should be noted that the results are intended to provide exploratory insights rather than statistical generalization. Additionally, the absence of standardized criteria such as the Prosthodontic Diagnostic Index (PDI) for case selection may affect the comparability and consistency of the cases analyzed [29]. Nonetheless, the theoretical framework identified here offers a foundation for establishing research hypotheses applicable to similar contexts.

6. Conclusions

Within the limitations of this study, the following conclusions were drawn:

1. Students' perceptions of teeth arrangement in clinical education revealed its utility, cost, and intrinsic value, with patient-specific tasks fostering authentic learning that enhanced understanding, motivation, and responsibility while increasing cognitive and emotional demands.
2. The non-digital support group faced challenges in independently applying theoretical knowledge, relied on limited visual and peer resources, and ultimately became highly dependent on repeated supervisor feedback for learning progress.
3. The digital and 3D resources enhanced students' confidence, fostered three-dimensional understanding, and supported reflective self-assessment by complementing traditional guidebooks with interactive and tangible references.
4. Structured supports—including sufficient time, close instructor guidance, theory–practice integration, and step-by-step written feedback—were proposed to enhance the effectiveness of denture teeth arrangement with digital support.

Data availability statement

Data supporting the findings of this study are available from the corresponding authors upon reasonable request.

Ethical approval

Ethical approval has been granted by the Yonsei University Dental Hospital Institutional Review Board (2-2022-0059).

Conflict of interest

All authors declare that they have no conflicts of interest related to the manuscript.

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