



RESEARCH ARTICLE

A 3D-PRINTED DIGITAL ASSET LIBRARY FOR REMOVABLE PROSTHODONTICS EDUCATION: DEVELOPMENT OF THE BALL-POINT EDENTULOUS IMPRESSION TRAY SYSTEM

Jacqueline Medina, D.D.S., FAAMP¹; Qian Chang Gallo, M.S.¹; Dalton Wilson, D.D.S.¹

¹Department of Reconstructive & Rehabilitation Sciences, College of Dental Medicine, Medical University of South Carolina, Charleston, SC, USA

Corresponding Author: Jacqueline Medina, D.D.S., FAAMP, Department of Reconstructive & Rehabilitation Sciences, College of Dental Medicine, Medical University of South Carolina, Charleston, SC, USA

e-mail: medinaja@musc.edu

Received: Jul 15 2026; **Accepted:** Aug 25. 2026; **Published:** Oct 22. 2026

Abstract

Background: Predoctoral removable prosthodontics education relies substantially on stock edentulous impression trays that may have limited size availability, recurring procurement requirements, and restricted adaptability to large or atypical arch forms. These limitations may create practical challenges in preclinical teaching and reduce opportunities for students to engage with digital fabrication workflows.

Innovation: This study introduces *Ball-Point*, a cost-effective, computer-aided design (CAD), 3D-printed digital asset library of edentulous impression trays developed for integration into predoctoral removable prosthodontics education. The system was designed to improve size availability, anatomical adaptability, reproducibility, and exposure to digital design and computer-aided manufacturing (CAM) workflows.

Methods: Commercial edentulous impression trays were evaluated as reference designs, digitally scanned, and redesigned using CAD software. The designs incorporated tissue stops, retentive slits, venting holes, scalloped borders, and a custom ball-point handle. Trays were fabricated using fused deposition modeling (FDM) with Polymaker PLA and PVA water-soluble support material. The fabrication workflow was standardized using an Ultimaker S3 printer and Ultimaker Cura version 5.13.0. The digital library consisted of mandibular and maxillary trays in small, medium, large, and extra-large configurations. The resulting designs were reviewed by prosthodontic faculty for anatomical appropriateness, usability, and curricular alignment.

Outcomes: The digital library enabled production of eight size-specific tray configurations, including large and extra-large designs intended to expand the size range available for educational use. When the complete eight-tray library was fabricated, 92.8 g of PLA and 76.6 g of PVA were consumed. Based on the material prices used in the study, the estimated total material cost was approximately US\$6.76 for the complete library. Individual tray material costs ranged from approximately US\$0.53 to US\$1.10. Faculty review indicated that the designs were anatomically appropriate and suitable for the intended preclinical application. These findings represent early-stage Phase I development and feasibility outcomes rather than formal educational effectiveness outcomes.

Conclusion: The *Ball-Point* digital asset library demonstrates a scalable model for integrating CAD and FDM-based digital fabrication into removable prosthodontics education. By maintaining digital rather than exclusively physical inventory, institutions may reproduce, modify, and distribute tray designs according to educational needs. Future Phase II studies should formally evaluate student learning, digital competency, confidence, engagement, and clinical preparedness following appropriate institutional ethical review.

Keywords: 3D printing; additive manufacturing; removable prosthodontics; complete dentures; dental education; CAD/CAM; digital dentistry; impression trays; FDM; curriculum development

1. INTRODUCTION

Preliminary impressions for edentulous patients represent an important step in complete denture fabrication because they provide an initial

representation of the supporting tissues and anatomical boundaries that subsequently influence custom tray design, border molding, definitive impression procedures, and prosthesis fabrication¹. Teaching these procedures to

predoctoral dental students therefore requires educational resources that allow students to understand both the biological principles of impression making and the practical relationship between anatomy and tray design.

In predoctoral education, stock edentulous impression trays are commonly used because they provide a standardized and readily accessible method for teaching preliminary impression procedures¹. However, conventional stock-tray systems may have limitations related to size availability, physical inventory requirements, repeated procurement, and adaptability to patients or teaching models with large or atypical arch forms. These limitations are particularly relevant in educational environments in which multiple students require access to trays of different sizes during repeated laboratory exercises.

The availability of appropriately sized trays is important because an inadequately sized tray may compromise impression-material distribution, tissue coverage, border extension, and the subsequent quality of the preliminary impression. In an educational setting, limited tray selection may also constrain students' ability to appreciate the relationship between arch anatomy and tray selection.

Commercial systems require institutions to maintain physical inventories and periodically purchase additional trays. By contrast, CAD and additive manufacturing technologies provide an alternative approach in which digital designs can be stored and reproduced when required. Three-dimensional printing has increasingly been incorporated into dentistry because it permits rapid fabrication of customized physical structures from digital data and can reduce material and production costs in selected applications^{5,7,8}.

FDM-based workflows are particularly attractive for educational environments because desktop FDM printers can fabricate polymeric components using relatively inexpensive thermoplastic materials. Previous studies have demonstrated the feasibility of using additive manufacturing for dental tray fabrication and have reported favorable dimensional characteristics and retention-related outcomes in selected experimental settings^{5,8,10}. These developments suggest that digital tray fabrication may be applicable not only to clinical workflows but also to dental education.

The integration of digital dentistry into predoctoral curricula has also expanded opportunities for students to develop competencies beyond traditional clinical procedures. Digital workflows can introduce students

to scanning, digital model manipulation, CAD design, file preparation, slicing, additive manufacturing, support structures, material selection, and post-processing. Such competencies may complement conventional prosthodontic instruction and prepare students for increasingly digital clinical and laboratory environments^{6,14,21}.

The educational relevance of digital workflows is further supported by the growing recognition that dental curricula need to incorporate contemporary digital technologies. Recent literature has described increasing use of 3D printing across dental education and identified the potential of additive manufacturing to support teaching in multiple dental disciplines⁹. Digital removable prosthodontic workflows have similarly been considered for integration into dental curricula²¹.

From a sustainability perspective, digital fabrication may also provide opportunities to reconsider the management of physical inventories. Instead of maintaining large numbers of physical tray configurations, institutions can retain digital assets and produce additional units when required. However, the sustainability implications of 3D printing are complex and should not be equated automatically with environmental benefit because material consumption, support material, energy use, equipment requirements, and disposal must also be considered. Therefore, sustainability should be regarded as a potential consideration rather than a demonstrated outcome of the present study.

The economic feasibility of FDM fabrication is another important consideration in educational settings. Previous investigations of dental 3D-printing workflows have reported potential reductions in fabrication time and consumable cost compared with conventional manufacturing approaches¹⁸. However, comparisons are highly dependent on printer type, material, design, labor, post-processing, and the specific dental application. Accordingly, the present study focuses specifically on material consumption and consumable cost rather than claiming a complete institutional cost advantage.

Historically, preliminary impression procedures have been taught using conventional physical trays and impression materials. Custom tray design features, including tissue stops and retentive elements, have been investigated for their potential effects on impression-material control and tray retention^{10,11}. Digital design platforms such as Meshmixer and other CAD environments provide additional opportunities to customize these features and standardize their dimensions across multiple tray configurations¹³.

The present project addresses an educational and practical gap by developing a standardized digital asset library of

edentulous impression trays that can be reproduced using FDM technology. Rather than treating impression trays solely as physical consumables, the *Ball-Point* system conceptualizes them as digital educational assets that can be stored, reproduced, modified, and incorporated into preclinical prosthodontics instruction.

Importantly, this study represents an early-stage **Phase I educational innovation and feasibility project**. It was not designed to determine whether the digital tray library improves student learning, competency, satisfaction, or clinical performance. The primary objectives were to develop the digital asset library, establish a reproducible fabrication workflow, characterize material use and consumable cost, and determine whether the resulting tray designs were suitable for curricular integration. Formal educational evaluation is reserved for Phase II.

2. Theoretical and Implementation Framework

The educational innovation was informed primarily by principles of **Kolb's Experiential Learning Theory**, which conceptualizes learning as a cyclical process involving concrete experience, reflective observation, abstract conceptualization, and active experimentation^{19,20}.

Integration of CAD design and FDM fabrication into removable prosthodontics education provides an opportunity to connect theoretical prosthodontic principles with concrete digital and physical experiences. Students may potentially move from understanding the biological and mechanical principles of impression tray design to observing the consequences of digital design decisions, analyzing the resulting physical product, and modifying the digital design in response. This relationship provides a conceptual basis for future educational implementation rather than constituting a measured outcome of the present Phase I study.

The project also incorporates the Kirkpatrick Model as a framework for future evaluation of curricular implementation²². The model provides a potential structure for assessing learner reaction, learning, behavioral transfer, and broader educational results following formal implementation. In the present study, these levels were not experimentally evaluated. Instead, they were incorporated into the project logic model to guide future Phase II investigation Figure 1.

In addition, selected concepts from the Consolidated Framework for Implementation Research (CFIR) informed consideration of implementation factors including adaptability, resources, feasibility, and

scalability^{23,24}. These concepts were used to guide planning for future implementation rather than as a formal implementation-science evaluation during Phase I.

3. Innovation Description

The *Ball-Point* Dental Tray Library was structured as a three-part educational innovation consisting of:

1. a standardized digital asset library containing multiple edentulous impression tray designs;
2. a reproducible CAD/CAM and FDM fabrication pipeline; and
3. preparation for integration into preclinical removable prosthodontics instruction.

Together, these components provide a framework for addressing limitations associated with conventional physical stock-tray inventories while introducing students to contemporary digital manufacturing concepts.

The digital asset library consists of eight digitally designed edentulous impression trays representing mandibular and maxillary anatomy in four size categories: small, medium, large, and extra-large. The digital approach allows the designs to be stored electronically and reproduced when needed rather than requiring permanent physical inventory of every configuration.

The innovation is therefore based on the concept of digital inventory rather than exclusively physical inventory. A digital design can potentially be reproduced multiple times, modified according to educational requirements, or adapted to other compatible FDM systems. This approach may be particularly useful for educational laboratories in which multiple students require identical or differently sized trays.

As a Phase I innovation, the project emphasizes development, feasibility, reproducibility, material consumption, and curricular readiness rather than formal educational effectiveness.

4. METHODS

4.1. Ethics Statement

This Phase I educational design and development project did not involve recruitment, intervention, assessment, or collection of identifiable information from students, faculty, patients, or other human participants. The work was limited to digital modeling, fabrication, technical documentation, and preliminary expert review of an educational asset library of edentulous impression trays.

Institutional clarification was obtained regarding the

status of the Phase I activity, and the project team retained the corresponding documentation. Based on that institutional clarification, the Phase I activity did not constitute human-subjects research requiring IRB review/approval under the applicable institutional framework.

No student or faculty participant was enrolled or evaluated as part of the Phase I development process. No educational performance data, competency assessments, satisfaction surveys, engagement measures, or identifiable participant information were collected.

Formal educational evaluation is planned for Phase II, when students and/or faculty will participate in evaluation of curricular implementation and educational outcomes. Appropriate institutional ethical review and, where required, IRB approval or determination will be obtained before initiation of Phase II activities involving human participants.

The distinction between Phase I development and Phase II educational evaluation was maintained throughout the project.

4.2. Study Design and Curriculum Context

This descriptive educational innovation study describes the development, fabrication, and early-stage curricular preparation of a digital impression tray asset library for predoctoral removable prosthodontics education.

The project was designed to address practical limitations associated with conventional stock

edentulous impression trays, including restricted size availability, recurring procurement requirements, limited customization, and reduced exposure of dental students to digital fabrication workflows.

The project was structured as a **Phase I development and feasibility initiative**. The primary objectives were to:

- 1. develop a standardized digital library of edentulous impression trays;
- 2. establish a reproducible CAD/CAM and FDM fabrication workflow;
- 3. characterize material consumption and consumable fabrication cost;
- 4. document the technical parameters required for replication; and
- 5. determine whether the resulting designs were suitable for integration into preclinical removable prosthodontics instruction.

The educational innovation, referred to as the *Ball-Point* Dental Tray Library, consists of eight digitally designed edentulous impression trays representing mandibular and maxillary anatomy in four size categories: small, medium, large, and extra-large.

The digital asset approach allows tray designs to be stored, reproduced, modified, and distributed without requiring institutions to maintain a physical inventory of every tray configuration.

The overall conceptual and educational logic of the innovation is presented in Figure 1, which illustrates the relationship among the digital asset library, fabrication workflow, curricular implementation, and planned future evaluation using the Kirkpatrick framework.

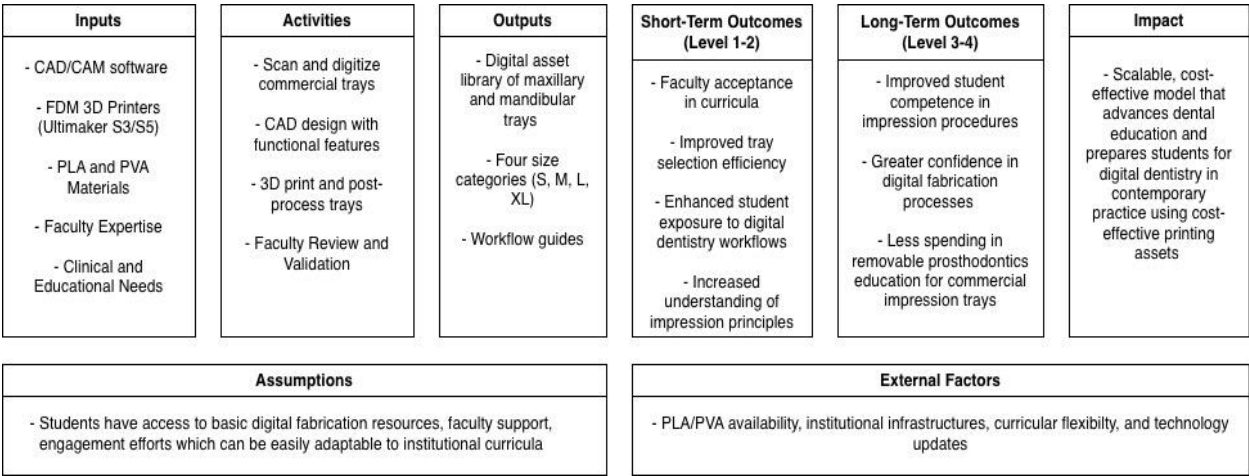


Figure 1. Logic model for the *Ball-Point* Impression Tray Library innovation. The model links digital asset development, FDM fabrication, curricular implementation, and planned future evaluation according to the Kirkpatrick framework, including Level 1 (Reaction), Level 2 (Learning), Level 3 (Behavior), and Level 4 (Results).

4.3. Digital Design and Development

Commercial edentulous impression trays were initially evaluated as reference designs. Physical dimensions and relevant anatomical characteristics of the reference trays were measured and digitally scanned using a 3Shape A/S digital scanning system to generate digital templates²⁵.

The resulting scan data were converted into stereolithography (STL) files and subsequently modified using computer-aided design software.

Autodesk Fusion 360 and Meshmixer were used for digital modeling, scaling, mesh refinement, and development of the final tray geometries¹³. The CAD/CAM development process included evaluation of overall tray dimensions, tissue adaptation, handle geometry, border configuration, retentive features, and impression-material space.

The principal design features incorporated into the *Ball-Point* library included scalloped borders, lateral retentive slits, standardized tissue stops, venting holes in maxillary trays, and a custom ball-point handle.

Tissue stops were designed with an approximately 2-mm height and 2-mm radius. For both maxillary and mandibular trays, tissue stops were positioned at the anterior midline and bilaterally in the first-molar regions to promote consistent impression-material thickness.

The custom handle consisted of a ball-point and neck configuration intended to facilitate functional movement of the lips and cheeks during border molding. The handle measured approximately 10 mm.

The mandibular tray handle was angled approximately 35° outward, whereas the maxillary tray incorporated a straight handle positioned at the level of the incisive papilla. These design characteristics were intended to facilitate functional movement during preliminary impression procedures.

The complete CAD/CAM development and fabrication pathway is illustrated in **Figure 2**.

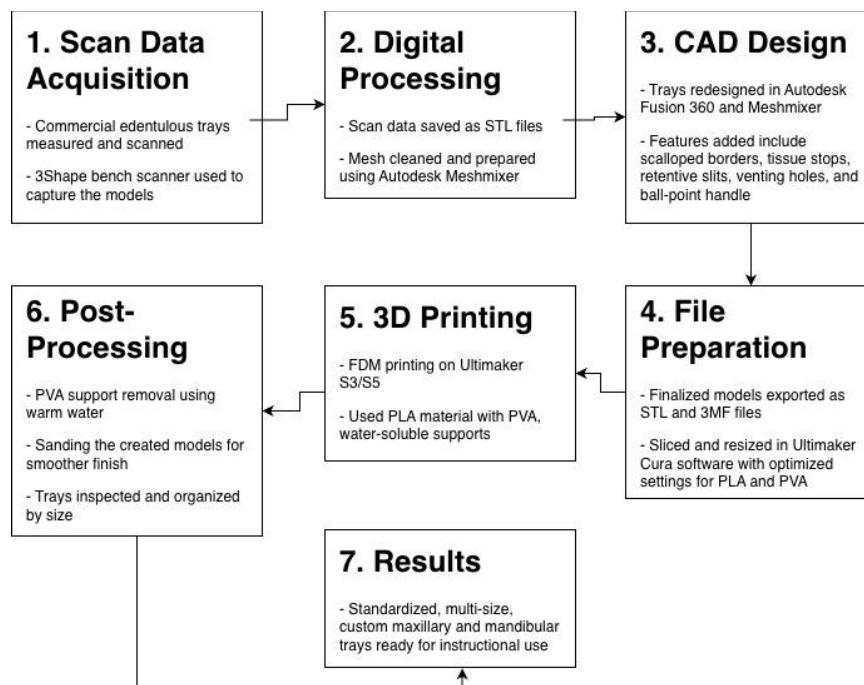


Figure 2. CAD/CAM and FDM workflow for development of the *Ball-Point* edentulous impression tray asset library. The workflow includes reference-tray acquisition, digital scanning, STL generation, CAD modification, dimensional standardization, slicing, FDM printing, support removal, post-processing, and preparation of the final tray library for curricular use.

4.4. Tray Dimensions and Digital Asset Library

The final digital library consisted of eight tray configurations: small, medium, large, and extra-large mandibular trays and small, medium, large, and extra-large maxillary trays.

The principal dimensions of each tray were recorded along the X, Y, and Z axes. The dimensions of all eight digitally fabricated trays are presented in **Table 1**.

Table 1. Dimensions of each edentulous impression tray in the custom *Ball-Point* Dental Tray Library

	X Dimension (mm)	Y Dimension (mm)	Z Dimension (mm)
Small Mandible (Size 11)	65.214	21.912	50.920
Medium Mandible (Size 9)	70.081	23.547	54.720
Large Mandible (Size 7)	78.841	26.491	61.560
Extra-large Mandible	80.363	33.577	65.000
Small Maxilla	66.710	27.815	53.436
Medium Maxilla	71.311	29.765	57.121
Large Maxilla	78.212	32.646	62.650
Extra-large Maxilla	80.185	23.517	62.000

The dimensions were evaluated using the standardized coordinate orientation established during the digital design process. The corresponding dimensional axes and the eight tray configurations were visualized in the digital environment and subsequently transferred to the slicing workflow.

4.5. FDM Printing Workflow and Reproducibility

The final tray designs were fabricated using an Ultimaker S3 fused deposition modeling printer. Polymaker PolyLite PLA with a 2.85-mm filament diameter was used as the primary printing material. Water-soluble PVA was used for support structures and build-plate adhesion.

The slicing process was performed using Ultimaker Cura version 5.13.0.

-

The standardized printing configuration consisted of a 0.2-mm layer height, 0.4-mm nozzle diameter, and 20% infill using a triangular pattern. Two wall lines were used, resulting in a 0.8-mm wall thickness. The nozzle temperature was maintained at 205°C, while the build-plate temperature was maintained at 60°C. The print speed was 70 mm/s.

Normal supports were used with support placement set to “Everywhere.” The overhang threshold was set at 45°, with 0.8-mm horizontal expansion. A PVA brim was used for build-plate adhesion. One tray was printed at a time.

The maxillary tray print time was approximately 2 h 42 min, while the mandibular tray print time was approximately 2 h 38 min. These values represent the workflow used in the present study and may vary according to tray size, geometry, printer condition, filament characteristics, and slicing configuration.

The orientation of the trays during printing was established in the Cura environment and is documented in Figure 3. The complete digital tray library, including maxillary and mandibular configurations in small, medium, large, and extra-large sizes, was visualized in the Cura software before fabrication.

Figure 3 therefore documents the actual digital preparation and slicing environment used for fabrication rather than serving only as a conceptual CAD illustration.

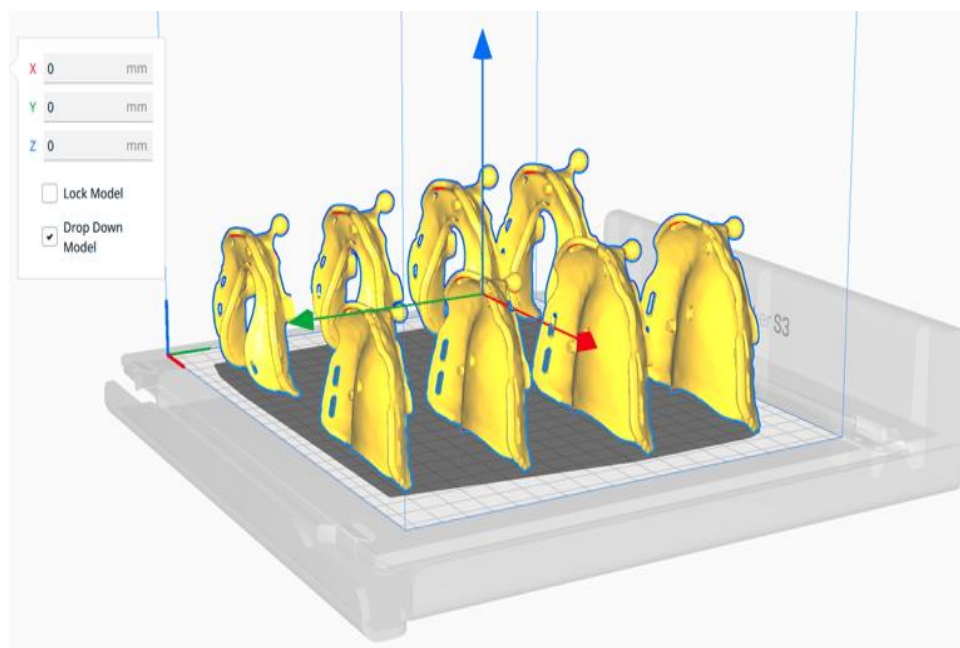


Figure 3. Maxillary and mandibular custom-designed 3D models from the *Ball-Point* Dental Tray Library in Ultimaker Cura, including small, medium, large, and extra-large configurations. The figure shows the digital orientation and slicing environment used for fabrication and corresponds to the printing parameters described in the reproducibility section.

The standardized printing parameters were:

- **Printer:** Ultimaker S3
- **Material:** Polymaker PolyLite PLA, 2.85 mm
- **Slicing software:** Ultimaker Cura 5.13.0
- **Layer height:** 0.2 mm
- **Nozzle diameter:** 0.4 mm
- **Infill:** 20%, triangular pattern
- **Wall line count:** 2
- **Wall thickness:** 0.8 mm
- **Nozzle temperature:** 205°C
- **Build-plate temperature:** 60°C
- **Print speed:** 70 mm/s
- **Supports:** Normal supports

- **Support placement:** Everywhere
- **Overhang angle:** 45°
- **Horizontal support expansion:** 0.8 mm
- **Build-plate adhesion:** PVA brim
- **Number of trays printed at a time:** 1
- **Approximate maxillary tray print time:** 2 h 42 min
- **Approximate mandibular tray print time:** 2 h 38 min
- **Printing orientation:** As shown in the Cura screenshots in Figure 3

This information was included to facilitate replication of the workflow by other dental schools and educational laboratories using comparable FDM equipment.

4.6. Post-Processing

Following FDM fabrication, the PVA support structures and PVA brim were removed from the printed trays. The trays were subsequently cleaned in agitated water to remove residual water-soluble PVA material.

After removal of the support material, the printed surfaces were mechanically smoothed by sanding until the trays reached a smooth surface condition appropriate for their intended educational use.

Post-processing was therefore standardized to include support and brim removal, water-based PVA cleaning, and surface smoothing.

The final appearance of representative fabricated maxillary and mandibular trays is shown in **Figure 4**.

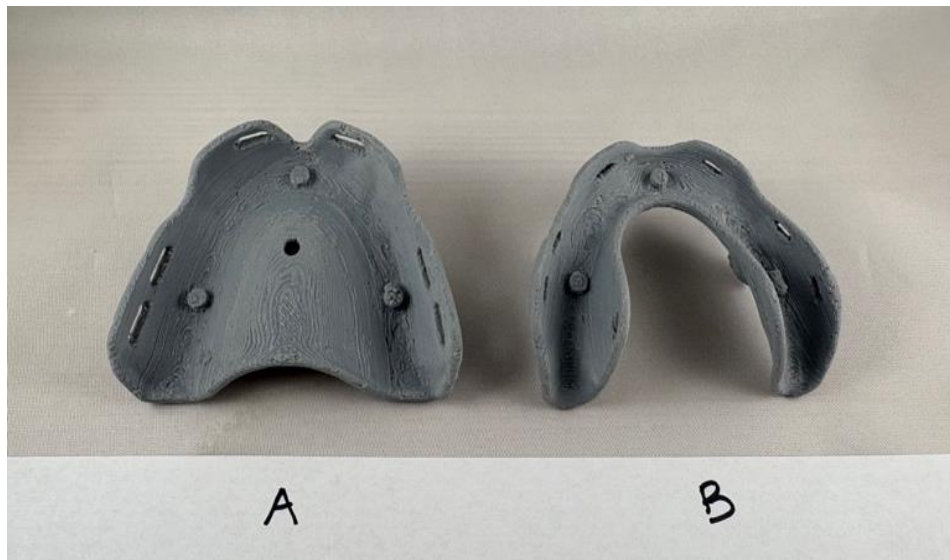


Figure 4. 3D-printed edentulous impression trays fabricated using an Ultimaker S3 from the *Ball-Point* Dental Tray Library. **A**, extra-large maxillary edentulous impression tray; **B**, extra-large mandibular edentulous impression tray.

4.7. Cost-Efficiency and Material Consumption

Material consumption and fabrication cost were calculated using Ultimaker Cura slicing software. The analysis incorporated PLA and PVA consumption and the corresponding material costs.

The complete library included eight tray models: small, medium, large, and extra-large mandibular trays and small, medium, large, and extra-large maxillary trays.

When all eight tray models were considered together, the total PLA consumption was **92.8 g**, while total PVA consumption was **76.6 g**.

-

The corresponding calculated PLA cost was approximately **US\$2.16**, and the PVA cost was approximately **US\$4.60**, producing a total estimated material cost of approximately **US\$6.76** for the complete set.

The detailed material consumption and cost calculations are presented in **Table 2**.

Table 2. Material usage and cost analysis for FDM-printed edentulous impression trays, including PLA and PVA consumption and estimated per-tray fabrication cost

Tray(s) printed on Bed	Amount of PLA (g)	Amount of PVA (g)	Cost of PLA (US\$)	Cost of PVA (US\$)	Total Cost (US\$)
All Trays (mandible and maxilla of all sizes: S, M, L, XL)	92.8	76.6	2.16	4.60	6.76
Small Mandible	9.2	9.0	0.21	0.54	0.75
Medium Mandible	11.4	10.2	0.26	0.61	0.87
Large Mandible	14.4	12.1	0.33	0.73	1.06
X-Large Mandible	15.5	12.3	0.36	0.74	1.10
Small Maxilla	6.9	6.1	0.16	0.37	0.53
Medium Maxilla	9.0	7.3	0.21	0.44	0.65
Large Maxilla	12.1	9.7	0.28	0.58	0.86
X-Large Maxilla	13.5	10.0	0.31	0.60	0.91

4. DISCUSSION

The *Ball-Point* trays were manufactured using 2.85-mm Polymaker PolyLite PLA filament. The retail price used for the calculation was US\$19.99 per 1-kg spool [29]. After accounting for the average container mass of approximately 140 g, approximately 860 g of usable PLA was considered available per spool.

Dynamism PVA filament was used as the water-soluble support material. The retail price used for the calculation was US\$59.99 per 1-kg spool [30]. Approximately 1 kg of usable PVA material was assumed for the cost calculation.

The material consumption values reported in Table 2 were derived directly from the slicing workflow and therefore represent the specific printing configuration used in this study.

The individual material-cost values were rounded to two decimal places; consequently, the sum of the displayed individual rounded values may differ slightly from the total calculated using the unrounded material-cost values. The reported US\$6.76 represents the calculated total material cost for the complete eight-tray library.

These results demonstrate that the digital library could be fabricated with relatively low consumable material requirements, with individual tray models requiring less than 16 g of PLA and less than 13 g of PVA.

Importantly, the present analysis represents a consumable material-cost estimate, not a comprehensive economic evaluation. Printer acquisition, maintenance, electricity, software, personnel time, post-processing labor, laboratory infrastructure, and equipment depreciation were not included.

4.8. Evaluation Strategy

Evaluation during Phase I focused on development, feasibility, reproducibility, anatomical appropriateness, usability, consumable cost, and readiness for curricular integration.

Prosthetic faculty reviewed the resulting tray designs for anatomical appropriateness, usability, and alignment with the objectives of preclinical removable prosthetics instruction. This review was considered an expert review process rather than a formal educational validation study.

Because Phase I did not involve student or faculty participants as research subjects, no student-level

competency, engagement, satisfaction, confidence, or learning-outcome data were collected.

The evaluation therefore focused on whether the digital asset library could be produced consistently, whether the printing workflow could be documented sufficiently for replication, whether the trays provided a range of potentially useful sizes, and whether the resulting products were suitable for integration into the intended preclinical learning environment.

Formal educational evaluation is planned for Phase II following appropriate institutional ethical review.

4.9. Results and Outcomes

The completed *Ball-Point* digital asset library consisted of eight edentulous impression tray configurations representing four mandibular and four maxillary sizes. The library provided small, medium, large, and extra-large options for both arches.

The dimensional data demonstrated systematic differences among tray configurations and provided a digital range of tray geometries intended to accommodate different arch dimensions. The measurements for each design are provided in **Table 1**.

The fabrication workflow successfully produced the planned tray configurations using the Ultimaker S3 FDM printer and Polymaker PLA. The standardized Cura configuration included a 0.2-mm layer height, 0.4-mm nozzle, 20% triangular infill, two wall lines, 0.8-mm wall thickness, 205°C nozzle temperature, 60°C build-plate temperature, and 70 mm/s print speed.

The use of PVA support material allowed the support structures and brim to be removed through water-based cleaning after fabrication. Following removal of the support material and sanding, the trays achieved a smooth surface condition suitable for their intended educational application.

The printing workflow required approximately 2 h 42 min for maxillary trays and approximately 2 h 38 min for mandibular trays. These production times demonstrate the feasibility of producing individual tray designs within a preclinical laboratory workflow, although actual production time may vary according to tray geometry and printer configuration.

The Cura visualization shown in Figure 3 documents the digital preparation of the eight tray models and provides a reproducibility reference for their

orientation and slicing configuration. Figure 4 demonstrates representative final printed products.

From an economic perspective, the complete eight-tray library required 92.8 g of PLA and 76.6 g of PVA, with an estimated total consumable material cost of US\$6.76.

Individual tray material costs ranged from approximately US\$0.53 to US\$1.10, depending on tray configuration and material consumption.

The expert faculty review indicated that the trays were anatomically appropriate for the intended educational application and that the designs incorporated features relevant to preliminary impression procedures, including tissue stops, retentive slits, scalloped borders, venting features in maxillary trays, and functional handles.

These findings represent Phase I development and feasibility outcomes rather than formal educational effectiveness outcomes.

4.10. Reproducibility of the Printing Workflow

Reproducibility was considered an important component of the Phase I development process because the educational value of a digital asset library depends not only on the availability of STL files but also on the ability of other laboratories to reproduce the physical products.

The authors therefore documented the printer, material, slicing software, layer height, nozzle diameter, infill pattern and density, wall configuration, extrusion temperature, build-plate temperature, printing speed, support settings, build-plate adhesion, number of trays printed per run, approximate printing times, orientation, and post-processing procedures.

The standardized workflow used an Ultimaker S3 printer with 2.85-mm Polymaker PolyLite PLA, sliced in Ultimaker Cura version 5.13.0.

A 0.2-mm layer height, 0.4-mm nozzle, 20% triangular infill, two wall lines, and 0.8-mm wall thickness were used. The nozzle and build plate were maintained at 205°C and 60°C, respectively. Printing was performed at 70 mm/s.

Normal supports were generated everywhere with a 45° overhang angle and 0.8-mm horizontal expansion. A PVA brim was used for build-plate adhesion. One tray was printed at a time.

The authors reported that maxillary trays required approximately 2 h 42 min and mandibular trays approximately 2 h 38 min.

After fabrication, the PVA supports and brim were removed, the trays were cleaned in agitated water, and the surfaces were sanded until smooth.

The printing orientation and slicing environment are documented in **Figure 3**. Together, these details provide a reproducible reference for institutions seeking to implement the digital tray library using an equivalent or sufficiently comparable FDM workflow.

Because FDM performance is influenced by printer hardware, nozzle characteristics, filament diameter, material formulation, environmental conditions, and slicing software, institutions reproducing the workflow may require minor parameter adjustments. The reported settings should therefore be considered the standardized parameters used in the present development process rather than universal parameters for all FDM systems.

5. DISCUSSION

This Phase I educational innovation demonstrates the feasibility of developing and fabricating a standardized digital asset library of edentulous impression trays for predoctoral removable prosthodontics education.

The principal contribution of the project is not simply the production of 3D-printed trays but the establishment of a digital workflow in which tray designs can be stored, reproduced, modified, and incorporated into a broader educational environment.

The availability of small, medium, large, and extra-large maxillary and mandibular designs addresses a practical limitation of relying on a restricted physical stock-tray inventory. In particular, the inclusion of large and extra-large configurations expands the range of digital tray geometries available for educational use.

The digital nature of the library also changes the logistical model of tray provision. Conventional systems require institutions to maintain physical inventory and periodically purchase replacement trays. In contrast, a digital asset library allows an institution to retain the design files and fabricate replacement or additional trays when needed.

This approach may reduce dependence on maintaining every physical tray configuration in inventory and may provide greater flexibility for educational laboratories. However, whether the approach produces actual institutional savings depends on equipment costs, personnel time, maintenance, material consumption,

electricity, and laboratory infrastructure.

The material and printing data supplied by the authors strengthen the reproducibility of the innovation. The present protocol documents the printer, material, Cura version, layer height, nozzle diameter, infill pattern, wall configuration, temperature settings, printing speed, support parameters, build-plate adhesion, print frequency, printing times, and post-processing procedure.

This level of technical documentation is particularly relevant for dental schools considering replication of the workflow.

The results also demonstrate that the digital workflow can be implemented with relatively modest consumable material expenditure. The complete eight-tray library required 92.8 g of PLA and 76.6 g of PVA, with a calculated total material cost of approximately US\$6.76.

Although material cost alone does not represent the total institutional cost of production, the low consumable requirement demonstrates the potential practicality of producing multiple tray configurations using an FDM-based educational workflow.

The printing times reported in this study also provide useful information for curricular planning. Approximately 2 h 42 min were required for maxillary trays and approximately 2 h 38 min for mandibular trays under the specified printing configuration.

Because fabrication can occur after printing has been initiated and does not necessarily require continuous operator presence, production could potentially be scheduled outside direct instructional periods. Nevertheless, operator supervision, printer monitoring, maintenance, and post-processing remain relevant considerations and were not quantified in the present study.

The post-processing workflow also has educational relevance. Removal of PVA supports and brim, water-based cleaning, and sanding provide opportunities for students and instructors to understand the relationship between digital design decisions and the physical characteristics of the resulting product.

These steps can reinforce concepts related to additive manufacturing, support structures, material behavior, surface finishing, and the transition from virtual CAD design to physical fabrication.

The innovation is conceptually consistent with experiential learning principles because students may potentially engage with a complete digital-to-physical

workflow rather than interacting only with a finished physical tray.

Within Kolb's Experiential Learning Theory, such a process may provide opportunities for concrete experience through fabrication, reflective observation through examination of the printed tray, abstract conceptualization through understanding CAD and prosthodontic design principles, and active experimentation through modification and reproduction of digital designs^{19,20}.

However, these educational mechanisms were not formally measured in Phase I and should therefore be regarded as the theoretical rationale for future implementation rather than demonstrated educational outcomes.

The use of a digital asset library may also facilitate institutional scalability.

Once appropriately reviewed and validated for the intended educational application, STL and 3MF files can potentially be shared among educational institutions, while fabrication parameters can be adapted according to locally available FDM equipment.

Differences in printer hardware, filament diameter, slicing software, material properties, and support systems may require parameter adjustment. The detailed protocol provided here nevertheless offers a starting point for replication.

Importantly, the present findings should not be interpreted as evidence that the *Ball-Point* trays improve student learning outcomes, technical competency, or clinical performance.

Phase I was intentionally designed as a development and feasibility study. No formal student competency assessment, learning assessment, satisfaction survey, comparative educational trial, or clinical performance evaluation was performed.

This distinction is important in interpreting the expert faculty review. Faculty review provides preliminary information concerning anatomical appropriateness, usability, and curricular alignment, but it does not establish educational effectiveness.

Formal student-level evaluation is planned as part of Phase II, for which the appropriate institutional ethical determination or approval will be obtained before participant involvement.

The distinction between Phase I and Phase II also addresses the ethical considerations associated with educational innovation. Phase I involved development and fabrication without human-subject participation.

Phase II will introduce formal educational assessment involving students and/or faculty and will therefore be conducted under appropriate institutional oversight.

Future implementation should evaluate whether students using the digital tray library demonstrate improved understanding of impression-tray design, greater confidence with CAD/CAM workflows, improved ability to select appropriate tray dimensions, greater familiarity with digital manufacturing concepts, and improved clinical or laboratory preparedness.

Future studies may compare conventional stock-tray instruction with digital fabrication-supported instruction using validated educational outcomes.

The Kirkpatrick framework provides a potential structure for these future evaluations²². Initial assessment could examine student and faculty reaction, followed by evaluation of learning, behavioral transfer to clinical or laboratory procedures, and longer-term educational or program-level outcomes.

Similarly, implementation factors such as compatibility with institutional infrastructure, faculty workload, student acceptance, cost, sustainability, and technological compatibility may be evaluated using implementation frameworks such as CFIR^{23,24}.

6. Implications for Dental Education

The *Ball-Point* digital tray library provides a model for integrating digital fabrication into removable prosthodontics education without requiring complete replacement of conventional prosthodontic teaching methods.

The innovation can be incorporated into preclinical laboratory exercises in which students first learn the biological and prosthodontic principles of preliminary impressions and then examine how those principles are translated into CAD geometry and FDM fabrication.

The library provides opportunities to introduce students to digital file formats, scanning, mesh manipulation, CAD design, slicing parameters, additive manufacturing, support structures, post-processing, and material selection.

These competencies are increasingly relevant as digital dentistry becomes more integrated into clinical and

The availability of multiple tray sizes may also allow instructors to demonstrate the relationship between arch anatomy and tray selection more effectively than a limited collection of commercially available physical trays.

For example, students could compare the geometry of small, medium, large, and extra-large configurations and discuss how tray dimensions influence impression-material space and anatomical coverage.

The digital asset approach also permits educators to reproduce specific tray configurations for individual teaching sessions without maintaining permanent physical inventories of all designs.

The relatively low material cost further supports potential implementation in educational environments in which repeated physical practice is required.

Digital assets can be reproduced when needed, potentially reducing dependence on fixed physical inventories.

At the same time, institutions should consider the complete workflow, including printer acquisition, maintenance, material management, post-processing, staff training, quality assurance, and equipment availability.

7. Limitations and Future Directions

Several limitations should be considered when interpreting the present findings.

First, this study represents a Phase I educational innovation and feasibility project and does not provide formal evidence of improved student learning outcomes.

Expert faculty review and feasibility assessment cannot substitute for controlled evaluation of educational effectiveness.

Second, the reported printing times and material consumption are specific to the Ultimaker S3, Polymaker PLA and PVA materials, Ultimaker Cura version 5.13.0, and the printing configuration documented in this study.

Other printers, filament diameters, slicing software versions, support systems, or material formulations may produce different results.

Third, the material-cost analysis reflects consumable costs and does not include equipment acquisition, maintenance, electricity, software licensing, personnel time, post-processing labor, or institutional infrastructure.

Therefore, the reported **US\$6.76 cost for the complete library should be interpreted as an estimated consumable material cost rather than a complete economic evaluation.**

Fourth, although the trays were reviewed by prosthodontic faculty for anatomical appropriateness and usability, formal clinical performance testing was not conducted as part of Phase I.

Future research should evaluate impression accuracy, retention, impression-material thickness, dimensional stability, tray rigidity, surface characteristics, and clinical usability under standardized experimental conditions.

Fifth, the current study does not establish whether digitally fabricated trays provide superior clinical or educational outcomes compared with commercially available stock trays.

Comparative studies are needed to evaluate the relative performance, cost, usability, durability, and educational value of the two approaches.

Sixth, the current study does not establish the environmental sustainability of the system. Although digital inventory may reduce some physical inventory requirements, the environmental impact of FDM fabrication depends on polymer consumption, PVA support material, energy consumption, failed prints, equipment use, and end-of-life disposal.

Future research could therefore evaluate the environmental as well as economic characteristics of digital tray fabrication.

Finally, Phase II educational evaluation is required to determine whether incorporation of the *Ball-Point* library improves student knowledge, technical competency, digital literacy, engagement, confidence, or clinical preparedness.

Such studies should be conducted following appropriate institutional ethical review and should include clearly defined educational outcomes, validated assessment instruments, appropriate comparison groups where feasible, and prospective statistical analysis.

8. CONCLUSION

A CAD-designed, FDM-printed digital asset library of

edentulous impression trays provides a feasible and potentially scalable approach to integrating digital fabrication into predoctoral removable prosthodontics education.

The *Ball-Point* library provides eight digitally reproducible tray configurations covering small, medium, large, and extra-large maxillary and mandibular designs.

The documented Ultimaker S3 and Cura 5.13.0 workflow, together with standardized PLA/PVA materials, printing parameters, support configuration, printing times, and post-processing procedures, establishes a reproducible fabrication pathway.

The complete library required 92.8 g of PLA and 76.6 g of PVA, with an estimated consumable material cost of approximately US\$6.76.

The availability of multiple digital configurations, including large and extra-large designs, and the ability to reproduce individual designs may address practical limitations associated with maintaining a fixed stock-tray inventory.

The digital workflow also provides an opportunity to introduce students to CAD, CAM, additive manufacturing, digital asset management, and the relationship between prosthodontic design principles and physical fabrication.

The present findings should be interpreted as **Phase I development and feasibility outcomes rather than evidence of educational effectiveness.**

Formal student and faculty evaluation is planned for Phase II under appropriate institutional ethical oversight.

Future research should determine whether this digital fabrication approach improves student learning, digital competency, clinical preparedness, and long-term curricular outcomes, while also evaluating clinical performance, economic implications, implementation feasibility, and sustainability.

9. Availability of Digital Assets

The *Ball-Point* digital tray library is available upon reasonable request.

STL and 3MF files may be obtained by contacting Dr. Jacqueline Medina at the Medical University of South Carolina.

The digital assets are intended to facilitate replication and adaptation of the workflow by dental educational institutions with appropriate FDM printing capabilities.

The digital files should be considered educational design assets and should be reproduced and modified according to the technical capabilities and institutional requirements of the receiving laboratory.

DECLARATIONS

Conflict of Interest

The authors declare no conflicts of interest.

Acknowledgments

The authors acknowledge the Medical University of South Carolina's institutional digital dentistry resources, including the DREAM Studio, and the technical support provided by Qian Chang Gallo during CAD design, digital modeling, FDM fabrication, and development of the *Ball-Point* Dental Tray Library.

Ethical Approval

Not applicable..

Funding

None.

REFERENCES

1. de Villa Camargos G, Armenine TE, Paleari AG, Nascimento GMO, Munhoz MFV. Teaching complete denture procedures to dental students by conventional or simplified methods: a randomized clinical trial. *J Dent Educ.* 2019;83:303-313. doi:10.21815/JDE.019.023.
2. Gershberg NC, Lee J, Murphree JK, Parchure A, Hackley DM. US students' perceptions on environmental sustainability in dental school. *J Dent Educ.* 2022;86:482-488. doi:10.1002/jdd.12824.
3. Alfaraj A, Alqudaihi F, Khurshid Z, Qadiri O, Lin WS. Comparative analyses of accuracy between digital and conventional impressions for complete-arch implant-supported fixed dental prostheses: a systematic review and meta-analysis. *J Prosthodont.* 2026;35:252-274. doi:10.1111/jopr.14094.
4. Carrière M, Prudentos JB, Lecigne A, Laran A, Nguyen CT, Destruhaut F, et al. Digital optimization of teeth setup in an edentulous patient with partial glossectomy: a case report. *J Prosthodont.* 2023;32:461-468. doi:10.1111/jopr.13685.
5. Priyadarshini KS, Nandini VV, Marimuthu R, Lathief J. Dimensional stability and retention strength of impressions to custom impression trays fabricated using conventional method and additive

- technology: an in-vitro study. *Indian J Dent Res.* 2023;34:427-432. doi:10.4103/ijdr.ijdr_519_23.
6. Elkasaby H, Touloumi F, Clark WA, et al. A survey on utilization and barriers of digital removable prostheses in US dental education. *J Dent Educ.* 2023;87:1746-1753. doi:10.1002/jdd.13372.
7. Tian Y, Chen C, Xu X, et al. A review of 3D printing in dentistry: technologies, affecting factors, and applications. *Scanning.* 2021;2021:9950131. doi:10.1155/2021/9950131.
8. Chen H, Yang X, Chen L, et al. Application of FDM three-dimensional printing technology in the digital manufacture of custom edentulous mandible trays. *Sci Rep.* 2016;6:19207. doi:10.1038/srep19207.
9. Karagkounaki A, Manoukakis T, Margariti I, Pavlou C, Hadjichristou C. 3D printing in dental education: a review of its use across disciplines. *J Dent Educ.* 2025;89:1479-1486. doi:10.1002/jdd.13876.
10. Deng K, Chen H, Wang Y, Zhou Y, Sun Y. Evaluation of a novel 3D-printed custom tray for the impressions of edentulous jaws. *J Dent.* 2022;125:104279. doi:10.1016/j.jdent.2022.104279.
11. Salem A, Elhadad FA. Evaluation of three different tray-impression retention techniques used in the final impression of completely edentulous cases. *Tanta Dent J.* 2025;22:475-480. doi:10.4103/tdj.tdj_146_25.
12. Carlsson GE, Ortorp A, Omar R. What is the evidence base for the efficacies of different complete denture impression procedures? A critical review. *J Dent.* 2013;41:17-23. doi:10.1016/j.jdent.2012.11.015.
13. Keshkiea NM, Jnaid FA. Evaluation of custom tray fabricated by CAD/3D printer compared with traditional technique for complete denture. *Teikyo Med J.* 2022;45(3).
14. Afshari FS, Sukotjo C, Alfaro MF, McCombs J, Campbell SD, Knoernschild KL, et al. Integration of digital dentistry into a predoctoral implant program: program description, rationale, and utilization trends. *J Dent Educ.* 2017;81:986-994. doi:10.21815/JDE.017.050.
15. Zeller AN, Neuhaus MT, Fresenborg S, et al. Accurate and cost-effective mandibular biomodels: a standardized evaluation of 3D-printing via fused layer deposition modeling on soluble support structures. *J Stomatol Oral Maxillofac Surg.* 2021;122:355-360. doi:10.1016/j.jormas.2020.09.018.
16. Zhao T, Weng Y, Li N, Gao Y. Clinical evaluation of computer-aided design and three-dimensional printing for completely edentulous mandibular custom tray fabrication: assessing clinician satisfaction. *Front Bioeng Biotechnol.* 2025;13:1556651. doi:10.3389/fbioe.2025.1556651.
17. Charasseangpaisarn T, Wiwatwarrapan C, Thunyakitpisal P, Srimaneepong V. Development of poly(methyl methacrylate)/poly(lactic acid) blend as sustainable biomaterial for dental applications. *Sci Rep.* 2023;13:16904. doi:10.1038/s41598-023-44150-2.
18. Yang X, Liu Y, Li Y, Zhao Y, Di P. Accuracy and feasibility of 3D-printed custom open trays for impressions of multiple implants: a self-controlled clinical trial. *J Prosthet Dent.* 2022;128:396-403. doi:10.1016/j.prosdent.2020.11.016.
19. Yüksel C, Uyaroglu ID. Experiential learning in basic design studio: body, space and the design process. *Int J Art Des Educ.* 2021;40:508-525. doi:10.1111/jade.12364.
20. Kolb DA. *Experiential learning: experience as the source of learning and development.* Englewood Cliffs (NJ): Prentice Hall; 1984.
21. Veerasamy A, Ghuloum F, Lo Y, van Vuuren WJ. Digital removable denture workflows in dental education: a systematic review and curriculum development exploration. *Eur J Dent Educ.* 2026;30:547-560. doi:10.1111/eje.70001.
22. Kirkpatrick DL. Techniques for evaluation training programs. *J Am Soc Train Dir.* 1959;13:21-26.
23. Drake CD, Lewinski AA, Zullig LL. Consolidated Framework for Implementation Research (CFIR). In: Ho EY, Bylund CL, van Weert JCM, Basnyat I, Bol N, Dean M, editors. *The international encyclopedia of health communication.* Hoboken (NJ): Wiley; 2023. doi:10.1002/9781119678816.ieh0944.
24. Reardon CM, Damschroder LJ, Ashcraft LE, et al. The Consolidated Framework for Implementation Research (CFIR) user guide: a five-step guide for conducting implementation research using the framework. *Implement Sci.* 2025;20:39. doi:10.1186/s13012-025-01450-7.
25. Kongkon P, Katheng A, Saiprasert P, Amornvit P. Complete dentures manufactured using CAD/CAM technology and a modified individual tray recording method. *Case Rep Dent.* 2025;2025:6224091. doi:10.1155/crid/6224091.
26. Stein BE, Yoon HI, Mattie H, Lee SJ. Quantitative analysis of the selective pressure impression technique using CAD-CAM technology: a pilot clinical study. *J Prosthet Dent.* 2022;128:1289-1294. doi:10.1016/j.prosdent.2021.03.026.
27. Kamio T, Iwata H, Kawai T. Challenges and solutions for cost-effective and practical dental cast fabrication with a desktop fused deposition modeling (FDM) 3D printer. *Cureus.* 2024;16:e73354. doi:10.7759/cureus.73354.
28. GDIT Inc. Massad overdenture low temp impression tray [Internet]. Massad Trays; 2026 [cited 2026 Apr 9]. Available from:

<https://massadtrays.com/products/massad-overdenture-low-temp-impression-tray>

29. Polymaker. PolyLite PLA functional PLA [Internet]. Polymaker; 2026 [cited 2026 Apr 9]. Available from: <https://shop.polymaker.com/products/polylite-pla>
30. Dynamism. Dynamism PVA 2.85 natural 1 kg [Internet]. Dynamism; 2026 [cited 2026 Apr 9]. Available from: <https://www.dynamism.com/dynamism/dynamism-pva-natural-285-1kg.html>



Copyright © 2026 by the author(s) and ASTRA SCIENCE LLC. This article is licensed under a Creative Commons Attribution-Non Commercial 4.0 International License (CC BY-NC 4.0). To view a copy of this license, visit <https://creativecommons.org/licenses/by-nc/4.0/>.