Benefits and Challenges of the Integration of Haptics-Enhanced Virtual Reality Training Within Dental Curricula.

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91   **CONFLICT OF INTEREST STATEMENT**

92   The authors declare that they have no known competing financial interests or personal

93   relationships that influenced the work reported in this paper.

94   **ABSTRACT**

95   **Background:** Haptics-enhanced virtual reality (VR-haptic) simulation in dental education has

96   evolved considerably during the past decade, representing a promising resource of simulation-

97   based training opportunities to support conventional practice. We aim to summarize current

98   literature on the applications of VR-haptics in learning, practicing, and teaching dental

99   education.

100   **Methods:** A literature search was performed using PubMed, focusing on research articles

101   published between January 2010 and January 2024. Out of the 667 articles that matched the

102   search terms (dentistry, education, haptic, teaching, training, virtual reality). 105 were screened,

103   and 42 were eligible for full text reading and utilization. Findings from an ongoing educator

104   survey on the use of VR-haptics in dental education have also been provided.

105   **Results:** VR-haptic simulation has been shown to have a supportive role in dental simulation

106   practice. Despite training within a digital world, hand skill transfer to the real world has been

107   demonstrated, which affords educators more flexibility in how to train their students before and

108   during traditional preclinical and clinical practical education. The individualized VR-haptic

109   training and feedback help students in mastering essential working techniques, while also

110   increasing engagement and motivation.

111   **Conclusions:** VR-haptics-supported dental education can help students effectively address

112   challenges during their preclinical and clinical training, as well as in their subsequent careers,

113   and it may help mitigate some weaknesses of the current educational system. Validation is a

114   key factor for the acceptance of VR-haptic simulators, thus, further research and verification is

115   needed before VR-haptics could be considered a primary hand skill development method of

116   learning in dental education. VR-haptic simulation may in the future be used as an assessment

117   tool for the students' and clinicians' credentialing process.

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119   **Keywords:** Evidence-based practice; Haptics-reinforced immersive learning; Manual dexterity

120   assessment; Simulation training

1 INTRODUCTION

Dentistry is a highly complex profession with long learning curves necessary for achieving optimal outcomes.[1] It has over 9,000 years of history, with excavated remains from the Indus valley yielding evidence of dentistry being practiced in the Neolithic age.[2] The earliest evidence of a dental restoration, made of beeswax, was discovered in Slovenia, and has been dated to be from 5800 years ago.[3] Although ancient, this scientific discipline is highly adaptive and has undergone numerous changes which have presented significant challenges in both training and measuring fine motor skill proficiency of students who are learning the dental profession.

Preclinical dental training exercises, whether they be in the form of observation or practice, have mainly been taught using real or synthetic teeth set placed in a phantom head since this methodology was introduced in 1894 by Oswald Fergus.[4] This highly practice-oriented, conventional didactic methodology has been widely utilized and emphasizes the central role of dental educators in the transferring of knowledge and practices with large amounts of theoretical content in a simulation environment.[5,6] However, given the advances in the past decades in digital technologies, and the adoption of student-centered curriculum design, this traditional landscape has slowly shifted to modern digital simulation. The first haptics-reinforced virtual reality-based dental trainer, Simodont, was developed through cooperation between the Academic Centre for Dentistry Amsterdam (ACTA) and Fokker Control systems, later Moog Inc. (Elma, New York, USA), and now owned by Nissin Dental Products Inc. (Kyoto, Japan), with the first finalized unit installed at ACTA in 2009.[7,8] Today, the unquestionable shift towards the adoption and integration of haptics-enhanced virtual reality (VR-haptic) digital technologies is evident.[9]

While this article will continue to use the term VR-haptics for the sake of internal consistency, these simulators belong under the umbrella of extended reality (XR), which is a comprehensive term that encompasses a variety of immersive technologies aimed at enhancing

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147 or altering our perception of reality through the integration of digital elements.[10,11] XR can be

148 classified into three primary categories: augmented reality (AR), mixed reality (MR), and virtual

149 reality (VR), in order of how much of what one sees only exists digitally. AR equipment overlays

150 digital elements over physical objects, MR devices enable these elements to interact, and in VR

151 all interactions happen in a digital space. Each of these technologies provides unique

152 experiences and applications, significantly impacting a diverse array of industries like education,

153 entertainment, healthcare, and training. Haptics, on the other hand, is a multidisciplinary field

154 dedicated to the science and technology of transmitting and interpreting information through

155 touch. This involves generating a variety of tactile sensations, typically either electronically or

156 mechanically, to enable users to receive feedback while interacting with different devices and

157 interfaces.[12] The term "haptics" originates from the Greek word "haptesthai", meaning "to touch,"

158 emphasizing its fundamental link to tactile perception. Different types of VR-haptic trainers are

159 now available in dental education training. Several major companies are competing in the

160 development of commercial VR-haptic simulators, including Acadental (Overland Park, KS,

161 USA), Nissin Dental Products, SIMtoCARE (Vreeland, Netherlands), UNI SIM (Portsmouth, UK),

162 and Virteasy Dental (Changé, France).

163   The benefits of VR and haptics-reinforced dental health education appear to be far-

164 reaching, providing much-needed assistance to students, clinicians, patients, and educators

165 alike.[13–16] VR-haptic simulation helps bridge the gap between theoretical visualization,

166 preclinical, and clinical hands-on training. Thus, it has the potential to overcome some of the

167 shortcomings of the current master-apprentice training model that has been used as a standard

168 in dental education. VR-haptic simulation emphasizes active learning and hands-on learning to

169 develop skills necessary for clinical procedures. Thus, it allows educators to guide students in

170 performing dental exercises within a standardized, VR-enhanced, safe, and risk-free digital

171 environment.[17–20] As material losses are no longer a factor while the students practice their fine

172 motor skills, VR-haptic simulation reduces students' anxiety due to fear of failure. With the help

173   of VR-haptic training, individualized learning is possible as teachers can freely focus on the

174   students who are in greater need of help. At the same time, fast learners can practice a higher-

175   level skill or focus on other skills. Students can independently practice on their own time and

176   pace, outside of teaching hours, as the simulators can provide real-time, objective feedback

177   based on the students' performances. In this context, the utilization of haptic simulators to

178   differentiate between students' proficiency levels and for performance prediction has the

179   potential to facilitate personalized training.[15] The VR-haptic environment allows for the

180   standardization of student experiences, and provides opportunities for objective and consistent

181   assessment. The benefits of VR-haptic practice lie in its relative casualness, the ability to try

182   again as many times as necessary, and the possibility of training at a time suitable for each

183   student. Haptics-based simulators offer visuo-haptic output to evoke sensorial experiences that

184   allow the user to receive tactile feedback based on the different properties of the simulated

185   objects, providing dentistry students experiences that are akin to what they might encounter

186   during real patient care. For specific clinical procedures, VR-haptic simulation can provide the

187   opportunity for realistic training of clinical situations as unique patient cases could be scanned

188   and uploaded into the system for students to train on prior to a real clinical encounter.

189   VR-haptic technology offers significant advantages in advancing dental education by

190   facilitating enhanced skill acquisition and boosting student confidence as discussed above.

191   However, challenges related to financial investment, integration into existing curricula, and

192   skepticism among educators remain barriers to its broader implementation.[21] A comparison of

193   the current advantages and challenges is summarized in Table 1. Opponents of VR-haptic

194   technology in dental education argue that it may lack the realism and nuanced tactile feedback

195   of hands-on practice with actual dental materials and patients, potentially leading to an over-

196   reliance on virtual experiences. It is believed that true mastery of fine motor skills in dentistry

197   requires extensive real-world practice that simulation may not adequately replicate, especially

198   for complex or unpredictable clinical scenarios. Furthermore, they contend that students may

199 become overly accustomed to the risk-free nature of virtual environments, which could lead to

200 hesitation or mistakes in real patient interactions. There are also concerns about accessibility

201 and cost, as VR-haptic systems can be expensive to implement and maintain, potentially limiting

202 access for institutions and students in lower-resourced settings. While noteworthy and important

203 to keep in mind, these critiques may become less relevant as VR-haptic technology advances,

204 refining tactile accuracy and cost-effectiveness. In fact, as research increasingly supports the

205 potential of VR-haptics to complement traditional methods, providing safe, flexible, and objective

206 skill-building environments, VR-haptics may ultimately be seen as an essential, rather than

207 supplementary, component of dental education.

208   Modern dental education needs to adapt to the new and different opportunities and

209 challenges presented by digital dental education methods and the "digital learners" of today's

210 increasingly digitalized world. The aim of this report is to present prior and current research in

211 the role of VR-haptics in dental education, identify and consolidate the knowledge that dental

212 health educators need to effectively implement its use in the curricula, and introduce

213 representative VR-haptics-supported educational programs and events.

214

215 **2 METHODS**

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217 A literature search was performed using PubMed to identify papers which have evaluated the

218 role that haptics-reinforced virtual reality-based devices play in learning, practicing, and

219 teaching in dental education. Combinations of the following search terms and subheadings were

220 considered appropriate for this investigation: dentistry, education, haptic, teaching, training, and

221 virtual reality. The publications chosen were restricted to those published between 2010 and

222 2024 that described dental education or training within the medical and dental sciences. Out of

223 the 667 identified articles, 105 (16%) were advanced to screening based on title/abstract, and

224 42 (6%) were eligible for full text reading and the creation of this narrative report. The searching

225   strategy to narrow down the list of candidate articles included keywords and phrases such as

226   "VR-haptic device", "cariology," "prosthodontics", and "oral surgery".

227   The selected articles focused on evaluating the educational effectiveness of haptics-

228   reinforced virtual reality-based training for dentistry or stomatology students/residents. These

229   criteria ensured that the studies specifically targeted the use and implementation of VR

230   technology in the dental education field, providing valuable insights into its impact on learning

231   outcomes in this specialized area of study. Only papers published in English were considered,

232   and articles that were not peer-reviewed were excluded.

233   The two-stage screening process used by our independent reviewers involved an initial

234   assessment of papers based on titles and abstracts against specific criteria. This method helped

235   quickly filter out irrelevant studies and allowed us to focus on those that met the criteria for

236   further evaluation. By streamlining the reviewing process in this way, reviewers could efficiently

237   identify potentially relevant research and save time in the overall screening process. After

238   passing the initial screening, papers underwent a full-text assessment in the second stage. This

239   in-depth evaluation ensured that only the most relevant and high-quality papers progressed

240   further in the review process. Moreover, manually analyzing the reference lists of selected

241   papers helped uncover additional relevant manuscripts that might otherwise have been

242   overlooked in the electronic database search or other grey literature sources. This meticulous

243   approach ensured a comprehensive review of the existing literature and helped to fill in any

244   potential gaps in the research findings.

245   In addition to the literary overview, we have attached some of the initial findings from our

246   ongoing educator survey on the use of VR-haptics in dental education (results are as of the 9th

247   of August 2024). An electronic survey was distributed to all members of the VR-Haptic Thinkers

248   Consortium and an additional 910 oral health care educators from around the globe. The aim

249   was to gather insights into their perceptions on VR-haptic training across various preclinical and

250   clinical dental courses. The voluntary survey included a variety of questions designed to assess

251 matters such as when VR-haptic technology is implemented during dental education and on

252 what courses, as well as the various curricular challenges encountered. This global study was

253 classified as a non-human subject program evaluation, and it adhered to the ethical guidelines

254 set forth by both the European and Finnish National Board on Research Integrity, with ethical

255 approval granted by the University of Eastern Finland Committee on Research Ethics under

256 reference No. 13/2023. The data collected from these anonymous surveys underwent blind

257 analysis following collection. In this additional way, we wish to present the current challenges in

258 the use of VR-haptics from the perspective of experienced educators all around the world. We

259 also list some of the suggested additions and improvements that the educators are currently

260 hoping for.

261

262 **3 RESULTS AND DISCUSSION**

263

264 **3.1 A new era**

265 The dental educational sector is poised for digital disruption and there has been a drastic

266 increase in the applicational scope of digital solutions in preclinical and clinical education

267 support around the globe. The field of VR-haptic simulation has seen rapid growth since 2009

268 when the Simodont VR-Haptic Dental Trainer was first introduced.[22] Along with the rise in their

269 utilization, VR-haptic training tools are becoming increasingly more realistic and sophisticated.

270 Their visual fidelity and user experience have significantly improved compared to what they

271 were just 10 or 5 years ago and, as a consequence, an increase in the use of practice modules

272 involving VR-haptics is likely to occur in the early dentistry curriculum.[23,24] Haptic technology is

273 especially appropriate during early dental manual skills training as VR-haptic training has been

274 shown to significantly increase the level of new students' basic technical skills and confidence,

275 even when only relatively simple models are used for practicing dental procedures. Despite this,

12

276   there is currently no consensus about the best methods and practices in using VR-haptics in the

277   various dental curricula.[25–32]

278

279   **3.2 Benefits of VR-haptics**

280   VR-haptics offers unique benefits and sustainable learning experiences and outcomes.[33,34] The

281   mission of VR-haptic dental training aligns with fostering a university training environment where

282   "the learner is the protagonist".[33] For example, it can enable more cost-effective dental

283   education by reducing the amount of direct contact hours required from the educators while

284   offering a more relaxed, independent training environment for the students within various dental

285   disciplines.[35] Virtual simulation allows students to work in a less stressful environment as they

286   can try the practices again and again unlimited times until they achieve their goal without the

287   risk of irreversible damage to simulated materials or human teeth while using a phantom head

288   or, even worse, performing on a real patient.[36] In this respect, it is acknowledged that before

289   starting patient treatment in clinical settings, dental students must demonstrate advanced

290   psychomotor skills, which could be acquired via VR-haptic based training. Typically, students

291   perceive VR-haptic simulation training as a transitional "bridge" connecting pre-clinical

292   instruction and clinical practice.

293   Certain VR-haptic dental simulators offer advantages such as ensuring proper

294   ergonomic posture by requiring students to look through a projector window screen, and

295   fostering a sense of competition by establishing targets for task completion at specified difficulty

296   levels within a constrained timeframe. The ability of haptic trainers to mandate indirect vision in

297   selected exercises has no equal analog in the physical world. Thus, this allows training students

298   to have appropriate body awareness and avoid potential chronic injuries from abnormal neck

299   and back posture while performing dental procedures.

300   The real-time individualized feedback helps improve students' confidence in their ability

301   while pinpointing the areas in their skills that still require more attention. In traditional settings,

302   students who are in need of extra training in manual dexterity skills often do not realize it

303   themselves. With the help of VR-haptic simulation, educators can offer them standardized as

304   well as additional or customized training to develop their hand skills to reach the average

305   expected dexterity level. It has also been shown that virtual simulation exercises enable skill

306   transfer to real-world settings. An important byproduct of utilizing VR-haptics is sustainability, as

307   the need for single-use materials and active water supply and waste management is

308   significantly reduced.

309   More importantly, many dental schools around the world find it more and more difficult to

310   get individuals to volunteer as patients for undergraduate training. The haptic system will, if not

311   give a fully clinical experience, at least mimic the clinical setting as close as is possible today.

312   Expanding the databases of VR-haptic systems with real clinical cases and synchronizing VR-

313   haptic training with phantom head-based simulations could represent a very promising

314   educational path; it is worth reiterating that VR-haptics provides the opportunity to simulate real

315   clinical scenarios before experiencing them with real patients. Consequently, the consolidation

316   of competency can be directed within a simulated environment, ensuring that patient care is

317   administered by clinicians with validated skills.[14]

318   Recently, it has been demonstrated that virtual dental simulation and haptics benefits

319   extend beyond developing practical skills to improving didactic knowledge and students'

320   confidence levels.[35] Applications of virtual dental simulation in dental education can span

321   undergraduate dental programs to advanced dental implant training, endodontic microsurgery,

322   and the planning of craniofacial and orthognathic surgery.[37–39] In addition to the numerous

323   applications listed above, we propose that virtual dental simulators also could be used as an

324   adjunct tool on an *ad hoc* basis for senior students that are struggling with certain aspects of

325   clinical practice.[40,41]

326

327   **3.3 Limitations to current VR-haptics**

328   The total number of dental schools worldwide is challenging to pinpoint with absolute accuracy

329   due to variations in counting methods and updates in the establishment of new institutions.

330   However, it is estimated that there are over 1,000 dental schools globally. Despite the unique

331   and attractive benefits of VR-haptic trainers, during the past few years they have so far been

332   installed in less than 15-20% of the dental schools around the world.[31] There are some obvious

333   reasons for this: Firstly, financial constraints: dental institutions have to allocate initial

334   investment funds and faculty "buy-in" time to facilitate the integration of digital dental simulators

335   in their preclinical setups. Secondly, the time commitment: expert dentists are needed to design

336   and create new evidence-based curricula that utilize the VR-haptic trainers. Thirdly, space

337   requirements: suitable facilities must be found for setting up training laboratories and the

338   associated resources. These three reasons are interrelated in that faculty time impacts finances

339   and space is costly. Additionally, while VR-haptic technology holds considerable potential to

340   improve dental educational experiences by fostering greater engagement, facilitating practical

341   skill development, and allowing personalized learning, the absence of cross-border

342   comprehensive evidence-based validation testing raises critical questions regarding its overall

343   effectiveness. To fully capitalize on the benefits of these new technologies in educational

344   settings and to address skepticism among educators, rigorous global research and the

345   establishment of standardized practices are required. Such an approach will be pivotal in

346   maximizing the impact of VR-haptics on dental education.

347   However, it is also important to highlight that there are still some limitations to virtual

348   dental simulation, such as the finger rest positioning as well as the absence of specific training

349   for light reflection and retraction of adjacent soft tissues using the students' non-dominant

350   hand.[42] Adverse physical (cybersickness/nausea) and mental (discomfort, fear) reactions are

351   also possible, though unlikely.[43] Furthermore, the applications of virtual dental simulation in, for

352   example, endodontic training are still limited and restoring teeth with crowns and fillings is

353   currently not supported either.[44] Although there are many VR-haptic simulators in the market,

354   the three most commonly used ones, Simodont Dental Trainer, DENTE Simulator, and Virteasy

355   Dental Simulator, have been discussed in Table 2 to showcase some of the features that are

356   and are not available (adapted and modified from Imran et al., 2021).[23,45]

357

358   **3.3 Summary of the advantages and limitations of VR-haptics**

359   Comparing VR-haptic training to traditional dental training methods reveals several advantages

360   and limitations to each approach, particularly in the context of dental education and other

361   practical skill training (Table 3).

362

363   **3.4 Implications for curriculum development**

364   There appears to be a sense of uncertainty surrounding the integration of VR-haptic devices in

365   dental education, particularly with the influx of new companies entering the market. VR-haptic

366   dental trainers must meet the expectations set on new teaching methods. Consequently, a need

367   for thorough evaluation and additional research has emerged to better understand the effects of

368   the implementation of these new educational tools across undergraduate and postdoctoral

369   curricula.[35] It has been reported that the integration of virtual dental simulation into dental

370   curricula should be planned in a strategic and methodological way in order to bridge the gap

371   between preclinical and clinical training, allowing for constructive alignment between the

372   different components of the dental programs.[25,26] In short, sufficient time and resources must be

373   invested.

374   Effective VR-haptics-reinforced dental education requires thorough curriculum redesign.

375   The integration should not be viewed as a simple technical conversion from phantom head-

376   based simulation to VR-haptic simulation. Dental faculty should evaluate whether to incorporate

377   VR-haptic components directly into all courses with traditional phantom head simulation, limit

378   them to specific disciplines, or even mostly just offer them as alternatives to students who

379   require additional practice or who might otherwise miss simulation laboratory training due to

380   unavoidable causes like illness.

381   Although VR-haptic education is likely to become more and more important for practicing

382   different case-specific tooth preparations, phantom head simulation laboratory sessions and

383   clinical training with patients should still remain an integral part of dental education. VR-haptic

384   technology should therefore not be seen as a replacement for but an integral adjunct of

385   conventional training using phantom head-based and clinical teaching.[27] One incentive for the

386   faculty to use haptic training as part of their student development is the opportunity for

387   immediate, consistent, and objective assessment. This is something students immediately

388   appreciate, and it creates a market pull dynamic.

389   When designing a new dental curriculum, regardless of the dental discipline, content

390   delivery needs to be tightly linked with the chosen conventional tools. Careful alignment

391   between learning tasks, outcomes, and performance measures must be maintained.[46,47] Our

392   results demonstrate a lack of consistency between the studies conducted in the field of virtual

393   dental simulation due the utilization of different technologies and educational protocols. Our

394   findings indicate the need for standardization between studies as well as the need for cross-

395   institutional studies which are deemed necessary to develop international guidelines in this field.

396   Finally, it is important to spread the message about virtual dental simulation amongst dental

397   educators who are still resistant or hesitant to implement this technology due to the fear of the

398   unknown and the challenges they face with change management.

399

400   **3.5 VR-haptic educator survey**

401   *3.5.1 Information on survey entries*

402   The future of VR-haptics-supported education holds great promise as the technology continues

403   to advance and becomes more accessible, allowing its applications in education and training to

404 expand significantly. There is great potential for this technology to revolutionize how students

405 learn and professionals train in a wide range of fields.

406   Through our ongoing educator survey, we have received replies from 228 dental

407 educators and researchers by early August 2024. The educator experiences gathered through

408 the VR-Haptic Thinkers' survey come from many of the top universities in the world (Figure 1).

409 This helps lend credence to the replies as: 1. Many employers often perceive degrees from

410 these institutions as indicators of quality education and preparedness. 2. Studying at leading

411 universities often exposes students to diverse cultural and academic environments. 3. Top

412 universities are often at the forefront of research and innovation.

413

414 *3.5.2 VR-haptics in dental education: reported challenges and improvement suggestions*

415 Roughly 25% of the respondents have provided freehand comments on challenges that hinder

416 the implementation and use of VR-haptic devices during preclinical and clinical phases. These

417 comments offer valuable insight into what needs to be improved to enable VR-haptics' effective

418 use in education, guiding future research and innovation in this field. Table 4 shows the top five

419 most common comments on hardware and software-related challenges. In addition, 56% of the

420 respondents gave direct suggestions for what needs to be added to VR-haptic devices. The top

421 five themes and examples of the suggested additions are shown in Table 5.

422   The most suggested enhancements for VR-haptic devices include additional training

423 scenarios, software improvements, and AI-based personalized training enhancements. These

424 upgrades would provide users with a more versatile and engaging training experience, while

425 tailoring their training to fit their individual needs. By incorporating these improvements, VR-

426 haptic devices could offer a more widely applicable, effective, and personalized training platform

427 for a range of dental applications.

428

429 **3.6 Future vision**

430   Substantial diversity exists in the purpose, structure, processes, and content of VR-haptics-

431   reinforced conventional dental education across the world. Only through collaboration can these

432   aspects be synchronized, and the challenges posed by VR-haptics in dental education,

433   research, and practice be mitigated. The first conference on the use of VR-haptics in dental

434   education, The VR-Haptic Thinkers Meetup, was held in November 2023. The success of the

435   meetup and the new connections enabled the formation of an international VR-Haptic Thinkers

436   Consortium in February 2024. With members from the American Dental Education Association

437   (ADEA), Association of Dental Education in Europe (ADEE), and other respected national and

438   international associations of dental health educators and researchers, the focus was set on five

439   major areas: performing cross-border cutting-edge educational research; providing support for

440   developing VR-haptic niches; promoting VR-haptics-supported curriculum development;

441   disseminating data via free, hybrid meetups; and deepening the discussion between the

442   members of the academics and industry.

443   To effectively disseminate and integrate VR-haptic technology in dental education,

444   educators, institutions, and researchers should undertake several strategic steps (Table 6).

445   These actions will optimize the use of VR-haptics, enhance learning outcomes, facilitate broader

446   acceptance and utilization of the technology within dental curricula, and expand the existing

447   evidence-based knowledge pool globally.

448

449   **4 CONCLUSION**

450

451   This report highlights the transformative potential of haptics-reinforced virtual reality training in

452   dental education. VR-based training offers standardized learning opportunities, fostering high

453   engagement and knowledge transfer to clinical practice. It addresses educator shortages and

454   enables flexible, individualized learning, with promising applications for future dental education.

455   VR-haptic scenarios enhance student learning experiences, particularly in times of restricted

456 face-to-face training like the COVID-19 pandemic. However, several questions remain

457 unanswered. Effective supervision and assessment are crucial, along with understanding

458 optimal instruction and feedback characteristics for skill transfer. Cost-effectiveness

459 comparisons and studies on decision-making improvement are needed. Rigorous research

460 standards and tracking performance are essential, along with integrating VR-haptic education

461 into workforce training and maintenance. Ongoing evaluation and dissemination of educational

462 outcomes are vital, as is exploring broader applications beyond current dental competencies.

463

473

474 **CONFLICT OF INTEREST STATEMENT**

475 The authors declare that they have no known competing financial interests or personal

476 relationships that influenced the work reported in this paper.

477

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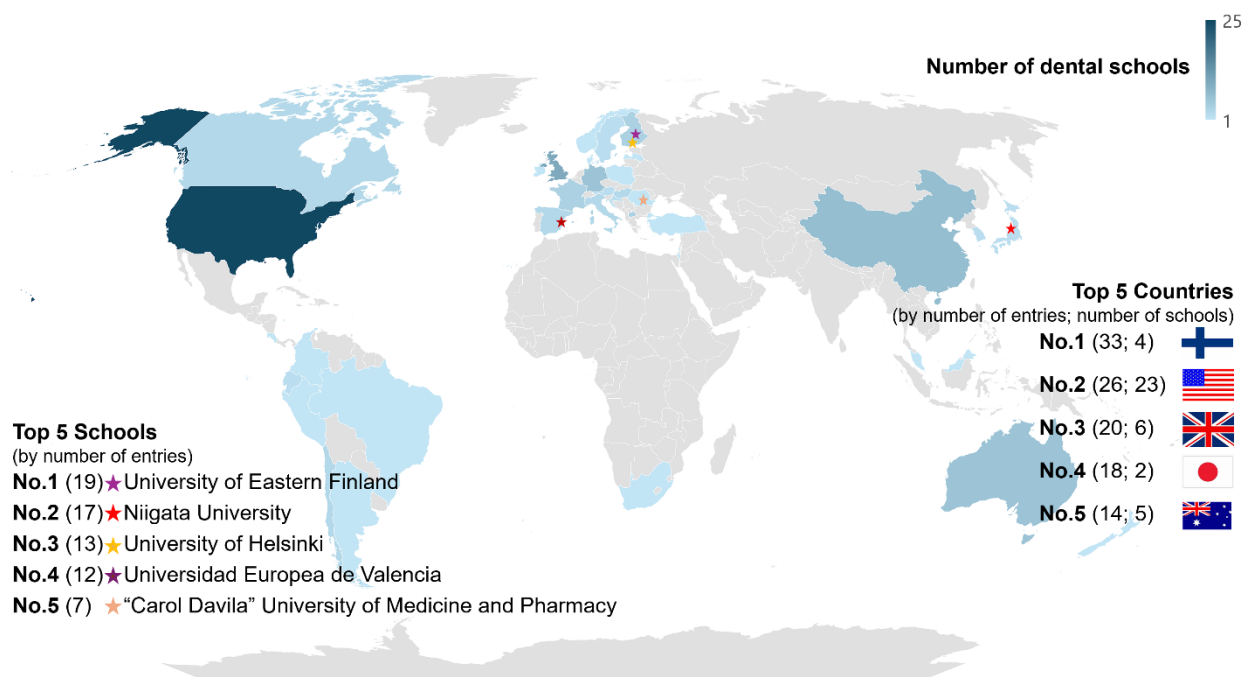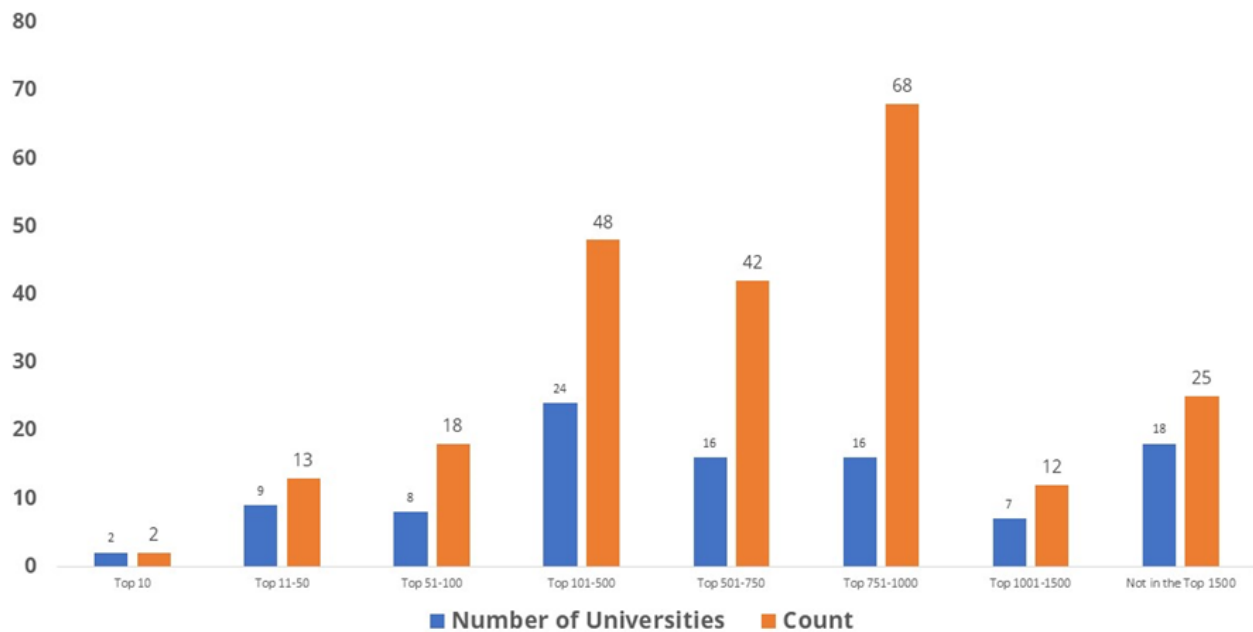
Figure 1 Graphical representations of the educator survey entries and their sources (as of early August 2024). The bar chart shows the number of survey entries (*n* = 228) from the QS World University Ranking 1-1500 universities. Respondents included 140 people who had DDS degrees, of whom 90 also reported having a PhD. There also were 60 responses from PhDs without DDS degrees. The map chart provides information on where the replies came from

24

596 geographically, as well as the top five countries and schools from which replies have been

597 received.

598

599 **Table 1**

600 A brief comparison of the current advantages and disadvantages of VR-haptics.

Positive outcomes	Opposing views
Enhanced skill development: VR-haptic simulators provide realistic tactile feedback, allowing students to practice dental procedures in a controlled environment. This feedback helps develop essential motor skills and hand-eye coordination, which are crucial for performing real-life dental tasks effectively. (Patil et al., 2023) **Increased confidence:** Many studies indicate that students who utilize VR-haptic technology report increased self-confidence in their abilities. The immersive training experience allows them to practice repeatedly without the risk of harming real patients, thereby enhancing their readiness for clinical practice. (Felszeghy et al., 2023) **Improved learning outcomes:** Research shows that combining traditional training methods with VR-haptic technology can lead	**Cost and resource allocation:** One of the significant barriers to widespread adoption of VR-haptic technology is the financial investment required for equipment and training. Many institutions face challenges in allocating funds and space for these advanced systems, which can limit their implementation. (Perry et al., 2017; Al-Saud, 2021) **Under-researched integration:** While there is enthusiasm for VR-haptic technology, the combination of these systems with traditional teaching methods remains under-researched. There is a need for more comprehensive studies to fully understand how these technologies can complement existing educational frameworks effectively. (Hsu and Chang, 2023)

to better learning outcomes. For instance, a study at the University of Eastern Finland found that students who practiced with VR haptics alongside conventional methods demonstrated improved performance in tooth preparation tasks. (Hsu and Chang, 2023) **Real-time feedback:** Haptic simulators can provide instant feedback on various parameters such as pressure and technique, allowing students to refine their skills and understand the nuances of different dental procedures. (Felszeghy et al., 2023) **Comprehensive training environment:** Advanced haptic systems can integrate diagnostic tools, enabling students to learn not just procedural skills but also critical thinking and decision-making related to diagnosing dental issues. (Huang et al., 2023)	**Limited availability:** Despite the benefits, fewer than 200 dental institutions worldwide have adopted VR-haptic equipment due to various logistical challenges, including the need for trained personnel and ongoing maintenance of the technology. (Serrano et al., 2023) **Skepticism among educators:** Some educators express skepticism about the effectiveness of VR-haptic training compared to traditional methods, questioning whether it can fully replicate the complexities of real-world dental procedures. (Patil et al., 2023)

601

602 **Table 2**

603 Comparison of the key features of different haptics-enhanced virtual reality simulators.

Feature	Simodont Dental Trainer	SIMtoCARE DENTE Simulator	Virteasy Dental Simulator
Type of device	VR-haptic	MR-haptic	VR-haptic
Allows ergonomic posture	Yes	Yes	No
Offers instant feedback	Yes	Yes	Yes
Allows educator to examine the exercises	Yes	Yes	Yes
Allows Wi-Fi connection	No	Optional	Optional
Allows the instructor to view the simulators live at the same time and record all exercises, their evaluation, and subsequent comments	Yes	Yes	Yes
Can be used by both right and left-handed users	Yes	Yes	Yes
Allows off-campus use	No	Possible (with an additional server)	Yes
The 3D images are realistic, but the texture of the healthy, decayed, and/or restored tooth still needs improvement	Yes	Yes	Yes
Device offers anesthesia, periodontics, and implantology exercises (in addition to dexterity exercises, restorative dentistry, pediatric dentistry, prosthetics, and endodontics)[a]	No	All	Periodontics, implants, and anesthesia
Simulation exam capability	Yes	Yes	Yes
Animated teeth	Yes	Yes (combination of virtual and real teeth)	Yes
Possibility of .dcm and/or .stl file upload for patient-specific scan virtualization and training	Yes	Yes	Yes
App for students	No	Yes	No

604 [a] As of May 2024

605 Adapted and modified from Imran et al., 2021

606

607 **Table 3**

608 Advantages and limitations of VR-haptic training

Advantages of VR-Haptic Training

Enhanced realism and immersion: VR-haptic training provides a more immersive experience by simulating real-world scenarios, while allowing learners to engage with content in a way that traditional methods either cannot provide or can't do so as readily. The integration of haptic feedback allows users to feel and manipulate virtual objects, enhancing the realism of the training experience.

Improved skills acquisition: Studies indicate that VR-haptic training can significantly enhance practical skills and theoretical knowledge. For instance, research has shown that students using VR-haptic simulators perform better in practical examinations compared to those undergoing traditional training methods. The tactile feedback helps in developing muscle memory, which is crucial for tasks requiring fine motor skills, such as dental procedures. (Koolivand et al., 2024)

Immediate and objective feedback: VR-haptic systems can provide instant feedback on performance, allowing learners to correct their mistakes in real time. This immediate evaluation is often lacking in traditional training environments, where feedback may be delayed or less specific. (Felszeghy et al., 2023)

Safety and cost-effectiveness: VR-haptic training eliminates many of the risks associated with real-world practice, particularly in high-stakes environments like healthcare. It also reduces costs related to materials and equipment needed for traditional training. (Koolivand et al., 2024)

Increased confidence: Trainees often report feeling more confident in their abilities after VR-haptic training. For example, a study found that VR-haptic learners were 275% more confident in their skills compared to those trained traditionally. (Felszeghy et al., 2023)

Limitations of VR-Haptic Training

Accessibility and cost of technology: While VR-haptic training offers many benefits, the initial investment in the technology can be high. Not all institutions may have the resources to implement VR-haptic systems, which can limit access for some students. (Leung et al., 2021)

Learning curve for technology: Some educators and learners may find it challenging to adapt to VR-haptic technology, especially those who are less familiar with digital tools. This can create a barrier to effective learning if not addressed properly. (Hsu and Chang, 2023)

609

610   **Table 4**

611   Educator survey: top five reported VR-haptic device-based challenges (as of early August

612   2024). Preclinical phase commenters (n = 58) included 53 people who had DDS degrees, of

613   whom 37 also reported having a PhD. Clinical phase commenters (n = 57) included 51 people

614   who had DDS degrees, of whom 36 also reported having a PhD.

Preclinical phase challenges
Devices missing clinical metrics and/or easily accessible real-time performance analysis options
Lack of high and low speed options for instrumentation
No voice feedback and/or voice controls
Better (possibly AI-powered) personalization options are needed
Insufficient realism/precision, the technology isn't "there" yet

Clinical phase challenges
Devices missing clinical metrics and/or easily accessible real-time performance analysis options
Insufficient realism/precision, the technology isn't "there" yet
Lack of high and low speed options for instrumentation
Transfer of real-life cases to devices and/or their utilization therein is too difficult
No voice feedback and/or voice controls

615

616   **Table 5**

617   Educator survey: top five reported suggestions for what should be added to VR-haptic devices

618   (as of early August 2024). Commenters (n = 127) included 99 people who had DDS degrees, of

619   whom 64 also reported having a PhD.

Addition suggestion themes	Examples
Additional training scenarios	Extraction, implantology, oral surgery, injections, anesthesia, periodontics, dental fillings, identification of caries lesions, flap design, tooth transplantation, root tip resection, calculus removal, etc.
Software improvements	More personalization options, voice feedback, voice controls, improved simulation of tissues, addition of surrounding structures, improved assessment options, easier upload and use of patient scans, etc.
AI-based improvements	Personalized training for students based on their strengths and weaknesses, automated performance assessment on both individual and group level, automated tutoring, etc.
Equipment improvements	Portable devices, high and low speed options for instrumentation, additional and more varied instrumentation for different training scenarios and treatments (lights, different grit sizes, etc.), cameras for tracking user posture, VR-headset use availability (in addition to 3D monitors), etc.
Gamification	Allow users to "play" against each other for high scores (speed, precision, etc.) both locally and globally over the internet, add cooperation possibility for simultaneous work on the same case, etc.

620

621   **Table 6**

622   Steps for the integration and optimization of the use of VR-haptics in the dental curricula.

<u>Curricular development and integration:</u>

Curriculum design: Collaborate to design curricula that incorporate VR-haptic training alongside traditional methods, ensuring a balanced approach that leverages the strengths of both. This includes defining when and how VR-haptic training should be introduced throughout the dental education program.

Pilot programs: Initiate pilot programs in select courses to evaluate the effectiveness of VR-haptic training and gather data on student performance and satisfaction. This will help in refining the institutional integration process based on empirical evidence.

<u>Faculty Training and Support:</u>

Professional development: Provide regular training sessions for faculty members on the use of VR-haptic technology, emphasizing its benefits and practical applications in dental education. This will help educators feel more comfortable and proficient in using the technology.

Peer collaboration: Encourage collaboration among faculty to share best practices, challenges, and successes in implementing VR-haptic training. Establishing a VR-haptic community spirit can foster innovation and continuous improvement.

<u>Research and Evidence Generation:</u>

Conduct studies: Engage in research to assess the impact of VR-haptic training on student learning outcomes, skill acquisition, and confidence levels. This research should also explore the comparative effectiveness of VR-haptics versus traditional training methods where possible.

Publish your findings: Share research findings through academic journals and conferences to contribute to the body of knowledge surrounding VR-haptic technology in dental education. Disseminating results will help encourage adoption by and validate the approaches of other institutions.

<u>Resource Allocation and Infrastructure Development:</u>

Investment in technology: Advocate for institutional investment in VR-haptic equipment and infrastructure to ensure adequate access for students. This may involve seeking external funding or partnerships with technology companies.

Student Engagement and Feedback:

Incorporate student input: Actively involve students in the development and implementation process by soliciting their feedback on the VR-haptic training experience. Understanding their perspectives can lead to improvements in and increased acceptance of VR-haptic technology.

Promote awareness: Educate students about the benefits of VR-haptic training and how it complements traditional methods. Highlight success stories and improvements in skills and confidence resulting from its use.

Networking and Collaboration:

Establish networks: Join or create networks of educators, researchers, and dental professionals interested in VR-haptics. This facilitates knowledge sharing, collaborative research, and collective advocacy for VR-haptic technology.

International collaboration: Engage in international discussions and meetups focused on VR-haptic technology in dental education to share insights, challenges, and innovations across borders.

Communicate with the manufacturers: Do not be afraid to contact and discuss issues and desired improvements in your VR-haptic devices with the manufacturers. Your feedback is essential in product development. If nothing else, discuss the challenges you have encountered within your peer network and collaborators so that a better understanding of what might be missing can be formed.

623