VR as innovation in dental education

Validation of a virtual reality environment: collecting evidence ‘on-the-fly’ during development and implementation

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Innovation in dental education: the ‘on-the-fly’ approach to simultaneous development, implementation, and evidence collection

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ABSTRACT

Introduction
This paper outlines an approach for education innovation and addresses the ambivalence between evidence-based and non-evidence based conditions. The ‘on-the-fly’ approach was described as involving implementation during the development of an innovation for dental education.

Materials and Methods
The ‘on-the-fly’ approach is illustrated by the process of designing and implementing cutting-edge technology of the MOOG Simodont Dental Trainer (DT) while systematically collecting evidence.

Results
Using the ‘on-the-fly’ approach for developing, implementing and collecting evidence simultaneously in an academic environment appears feasible in serving both the professionals, users as well as developers and system designers. During the implementation of the new technology, growing evidence stepwise strengthened its position; therefore, showing stakeholders that evidence was used to improve the technology seemed to support and increase acceptance of the new technology.

Conclusions
When pioneering an innovative technology in a specialty field, the development stage often precedes evidence for its effectiveness. Consciously choosing the ‘on-the-fly’ approach clarifies to stakeholders in advance about the lack of evidence in an innovation and the need of their support to collect such evidence for improvement and in order to facilitate implementation.
INTRODUCTION

*Improving dental education through technological innovation*

Continuous advancement in information technology—particularly in dentistry and medicine—has produced valuable technological innovations related to clinical activities, such as digital scanning, computer-aided design and manufacturing, digital radiography, and digital patient records. These developments affect not only the quality of care but also the design of dental curricula. Ideally, the dynamic nature of a dental curriculum means that it is continuously developing, and this process of continuous development involves addressing critical issues for improvement within an existing curriculum while, at the same time, creating opportunities for the improvement of instructional quality. Recently, new technologies have entered the dental education market, which resultantly have also increased the opportunities to address the challenges in the complexity of dental curriculum design. More specifically, these technological innovations offer a powerful catalyst for further development of a dental curriculum and revision of traditional teaching methods.

These days, dental curricula are often developed in response to an urgent problem. For example, current dental training is facing a major issue regarding the growing scarcity of human extracted teeth and suitable patients with the right dental needs for students’ education.\(^1,2,3\) Therefore, on such condition that dental training is dependent on the availability of specific extracted teeth and patients with specific procedures, this scarcity may prevent students from acquiring the necessary skills and competencies within the limited time for training to develop into confident qualified practitioners.

A virtual reality environment (VRE), which replicates real-world dental pathologies and the tools used to treat those pathologies, offers tremendous opportunities for dental education as training becomes independent from the availability of specific patients and models. In accordance with the ‘rules of art’, use of such VRE must be substantiated by scientific evidence—without such evidence, an academic environment will disincline to incorporate the new technologies into their program.\(^4\) More specifically, most educators need confirmation that the technology adds more value in comparison to their current method before they would be willing to implement it into their program. From the awareness of the need for evidentiary justification for such technology use as well as the need for systematic evidence generation and compilation, especially when the innovation is disruptive in nature, a specific approach was chosen, namely, the ‘on-the-fly’ approach to gather evidence on the design and implementation of a VRE. Generally, the commercial sector develops from a technology driven perspective a product for the market, arising from consumer need; however, its eventual implementation in education happens only after the product has proven its value. In cases where the innovation arises from an educational need and initiated by academic experts on the content, and is developed in cooperation with a commercial partner, the ‘on-the-fly’ approach may be used.
The ‘on-the-fly’ approach of a VRE development is characterized by simultaneous development and stepwise implementation, while gathering evidence to find the answers that educators need. However, this does not imply that the starting point for the development of a VRE is a ‘wild guess’. Rather, the development is based on prior expectations, assumptions, knowledge, and experiences derived from other learning environments, both virtual and otherwise. The decision to implement an educational method in such a fashion has diverse and fundamental implications applicable not only to a VRE for dental education, but also to applications of new technologies in other (educational) fields. Requiring sufficient scientific evidence before a VRE introduction and implementation can make its effective and timely development complicated, and even impractical. Moreover, the evidence value is limited, as it is not gathered in an authentic environment specific to its design. This makes the ‘on-the-fly’ approach—wherein evidence is gathered gradually from implementation, evaluation, and further development of the innovation in the actual environment for which it is designed—a meaningful and practical way forward. With this approach, the innovation per se and its lack of evidence are not in conflict; rather, they are interdependent and complementary variables.

This paper illustrates the application of the ‘on-the-fly’ approach through simultaneous stepwise development and implementation of the Moog Simodont Dental Trainer (DT) (Moog Inc. Nieuw-Vennep, The Netherlands) into a dental education curriculum.

**MATERIALS AND METHODS**

Figure 1 shows the model of the ‘on-the-fly’ approach, in which a technological innovation was designed, described, and applied during the process of developing, implementing, and generating evidence.
Figure 1. The ‘on-the-fly’ approach for development, implementation, and creation of evidence for an innovative technology.

Process of developing, implementing, and generating evidence for an educational innovation

The ‘on-the-fly’ approach consists of 3 phases:

Phase 1: Stepwise development where the innovation was launched prior to its complete (technical) development to introduce stakeholders to a new learning environment;

Phase 2: Stepwise implementation into the curriculum allowed the stakeholders to gradually adapt to the technology and bring them aboard in the process by using the innovation as an addition to the existing curriculum;

Phase 3: Systematic generation of evidence without a selection bias by first collecting evidence from a small group of students and later a whole cohort.6
In the following section, the three phases will be illustrated by describing the development and implementation of the DT at the authors’ dental school.

The DT is a device, which serves as a VRE that allows dental students to drill into virtual teeth and objects, and treat virtual patients using a haptic instrument that generates the feeling of working with real teeth (Figure 2). The DT consists of a training console in which students can work in the VRE and a computer that provides a virtual waiting room with theoretical content.1, 2, 7

![Figure 2. A Moog Simodont Dental Trainer](image)

The ‘on-the–fly’ approach applied to the DT

Phase 1 — Stepwise development

1. The development began with an idea arising from an observed educational need or desire in the curriculum. The idea for the DT was generated due to the increasing challenges in dental education at the authors’ school (see Introduction), and existing virtual or augmented reality systems could not solve the above-mentioned problems.8

2. The idea was supported by existing literature and expectations on the possibility of using contemporary and future technology. Then, assumptions were derived based on student learning and skill acquisitions in a VRE. The DT concept was delineated and believed to be a solution in addressing the problems mentioned, while encouraging student autonomous learning.7

3. Multiple brainstorming sessions were scheduled with all stakeholders to collect input for the development.
4. The brainstorming sessions, then, led to further search in the literature, adjusted expectations and assumptions, and the new development.

**Steps 1–4 are cyclical to concretize ideas to address the reasons for innovation.**

**Phase 2—Stepwise implementation**

5. The actual designing and building of the innovation was performed to meet the standards set in Phase 1.

6. Once the prototype has been developed, testing on a small scale was performed in a laboratory to generate feedback and perform preliminary research and therewith creating evidence.

7. Based on the received feedback from the small-scale testing, stepwise implementation in the curriculum, and the evidence obtained so far, the innovation and its base assumptions were continually developed, adjusted, expanded, and improved. The introduction of an educational innovation requires a period for establishing acceptance before a complete rollout. Therefore, stepwise implementation in the curriculum is justified with the development and therewith improvement of the DT as a continuing process.

The following presents the essential DT implementation steps for support in the school:

- The Board of Examinations nominated the dental trainer as part of the curriculum.
- An educational program was designed by the education management and professors of the departments involved.
- The teachers were tasked to use the dental trainer in the new module.
- Both management and teachers supported the decision to use the dental trainer.

8. Finally, large-scale testing with the innovation in the curriculum is performed—this is a major opportunity for the creation of evidence. Large scale testing was scheduled for the manual dexterity exercises in the first year of the curriculum, including the whole cohort to prevent selection bias. To ensure that the DT research, conducted throughout its implementation, is ethical and that no students should experience any disadvantages, approval from the ethical commission of the university and written informed consent from students were obtained (each new round of development pre-requires this ethical standards of practice). The dental trainer was initially complementary to traditional education; then, after some years, it was used as a total replacement in the manual dexterity course, wherein students practiced their control over the air rotor and developed fine motor skills.

**Phase 3—Generation of evidence**

9. Based on the obtained evidence and user feedback, the original and constantly arising new developmental ideas were be applied, adjusted, and merged to maintain focus on the development of a feasible instrument.

10. The development continued alongside the use of the innovation in the curriculum. Feedback was constantly collected and used for further development, improvement, and
adjustment of the innovation. Furthermore, the system’s version control was essential to enable concurrent development and use to complement each other. Evidence from the usage data was created and applied directly to the further development and new versions of the DT.

11. Ultimately, the innovation could be completely rolled out to the commercial market and reached its final implementation into the curriculum. Over time, newer improved versions of the innovation entered the market with more advanced features. However, feedback is still collected, thus un-limiting the VRE possibilities beyond improving what already is available.

The benefits of the ‘on-the-fly’ approach are not limited to the development of a complete new technology; in fact, it has been used for every aspect newly added to the DT, for both the software content in the VRE as well as the hardware production. The development of virtual teeth, stepwise implementation, and generation of evidence can be used to demonstrate the applicability of the ‘on-the-fly’ approach on a small scale. Virtual teeth were developed based on an educational need as there has been a prevalent shortage of human extracted teeth with the right dental pathologies. Then, the DT’s implementation into the curriculum on a small scale followed, and feedback was collected from the users, namely students, teachers, and dentists. Responses from the users indicated that the use of virtual teeth is appreciated more than the available plastic teeth, thereby providing scientific support and basis to further improve the development of virtual teeth (e.g., higher resolution, more realistic pathology, more realistic colours, and standardisation in hardness) and its implementation in dental education.

Bottlenecks for curriculum innovation

For a curriculum to expand and continuously assure quality, it must be dynamic, and involve continual adjustment to its content and pedagogy to include new research findings and to meet the changing needs of health professionals in training.10 The introduction of the DT in the dental curriculum enhanced this statement as it aimed to improve the quality of education dynamically and produce new evidence continuously. A major focal point for the DT implementation in the curriculum is the teachers, who play an integral role in successfully introducing the DT. Specifically, their exemplary role in instruction affects considerable influence on users’ attitudes. Furthermore, it is essential to manage properly the introduction of the new technology because such move can easily bring users out of their comfort zone by putting technology in between them and their existing world. The loss of comfort during the implementation process may result in initial rejection, with the argument of evidential insufficiency. Therefore, specific attention was given to mitigate hurdles in stepwise implementation.

A school, furthermore, has to deal with strict regulatory and legal requirements and any curriculum innovation or change must fit and adhere to the protocols, prioritizing end-users’ expectations from the innovation.
To promote its acceptance and thus the success of the introduction, expectations and experiences of teachers and students were followed meticulously. Unfortunately, these data were un-publishable, mainly due to too many confounding factors, but useful information was generated for the management and development. Based on these data, the implementation pace of the dental trainer was adjusted, as was previously done for the development of the Objective Structured Clinical Examination (OSCE).\(^1\)

Gartner’s ‘hype cycle’ (Figure 3) offers some insight into the implementation process of innovations.\(^2\) It represents the five phases that a technological innovation undergoes before acceptance:

1. **Technology trigger**: a product is introduced
2. **Peak of inflated expectation**: expectations about the product reach a peak
3. **Trough of disillusionment**: these expectations are not immediately met and disappointment follows
4. **Slope of enlightenment**: continuation and maturation of the development
5. **Plateau of productivity**: the innovation is accepted and its use stabilizes.

Thus, being able to ascertain the dental trainer’s position on this curve was crucial in managing stakeholders’ expectations. Notably, each new addition or change to the dental trainer followed Gartner’s cycle on its own. By acknowledging and ultimately mastering the hype cycle as well as the disappointment levels, the depth and width of the stages in the cycle could be managed.\(^2\) It is important to realize that the cycle applies to each change or new concept that is added to the innovation.

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**Figure 3. Diagram of Gartner’s hype cycle.**
Because the data were collected at the school developing the innovation, the curve described in Figure 3 may be more extreme than when a new customer would be introduced with the DT in their curriculum—in the latter case, the deepest trough of disillusionment in the cycle is most likely already smoothened out, as the development is further along than at the beginning. Figure 4 shows some of the factors that should be considered while implementing new technologies in a curriculum. Each change or addition to the innovation can be a hurdle for acceptance; hence, a necessary solution would be using coping strategies, for example providing information (Figure 4).

Figure 4. Factors in the implementation of a new innovation into a curriculum.

‘On-the-fly’ collection of evidence on the DT
In terms of the ‘on-the-fly’ approach, collection of evidence is paramount. In the authors’ school, studies, to-date, have been concerned with the following:

• Development of virtual teeth: Virtual teeth were created from Cone beam CT scans of human extracted teeth. The creation of virtual teeth with and without pathology has numerous benefits for dental education in terms of safety, cost, and usability.

• Evaluation of virtual teeth: The virtual teeth developed in the previous study were evaluated among dentists, teachers (also dentists), and master’s and bachelor students. The results indicated that the appearance of the virtual teeth was considered more realistic than the appearance of plastic teeth. Thus, the learning value with virtual teeth was expected to be better.

• Evaluation of students’ performance and preferences when working with three-dimensional (3D) or two-dimensional (2D) vision. Using 3D vision in the dental trainer had a significant positive effect on students’ performance and their appreciation of the trainer itself.

• Evaluation of the effect of force feedback (FFB) on performance and appreciation. It was found that FFB was necessary for adequate performance in using the dental trainer.
Evaluation of skill transfers from virtual reality (VR) to reality. Skills, developed using the dental trainer, were transferred to real examinations; thus, the dental trainer appeared useful for developing dental students’ manual dexterity.\textsuperscript{15}

A comparison of the performance results between student-determined manual dexterity testing moment and school-assigned testing moment showed that if students determine their own testing moment, their passing rate increased compared to if a school scheduled the testing time.\textsuperscript{16}

Selection bias was minimized in the population of all the investigations above because the student-participants in these experiments had equal education and experience level.

RESULTS

After the use of the ‘on-the-fly’ approach, the following results and experiences pertaining to its implementation were found based on the collection of feedback and other evaluation methods described in the preceding section:

- The school should have the ability and manpower capacity to be in control of the process of development, driven by an education need. Control is achieved by guarding boundaries to ensure the feasibility of each step in the development and clearly defining the result of each intermediate step of the process.

- The approach provides a model for the application of a stepwise implementation into the curriculum and, subsequently, a stepwise introduction of a new technology to the stakeholders.

- The ‘on-the-fly’ approach seems a feasible method to serve both professional users and program developers to continue improving the system. During the implementation stage, the cumulative evidence stepwise strengthened the position of the new technology. Showing stakeholders that evidence was used to improve the technology supported and increased acceptance of the new technology.

- The approach demonstrated the participating institution’s ability to retain the dynamicity of a curriculum and at the same time, to take acceptable risks by pioneering in a specialty field through a series of priority studies to gather scientific evidence to support the educational innovation.

- The approach demonstrated the possibility of innovation with concurrent stages of innovation, development, and evidence collection in a running curriculum within an academic environment in a responsible manner, without disadvantaging the student users.

- The approach showed that the necessity for regular updates to all stakeholders to garner support of the innovation and increase acceptance. The essential part of the ‘on-the-fly’ approach, namely, stepwise implementation with stepwise development, in applying the
results of collected evidence in further DT development and improvement was a cyclical process that repeated itself during all new technical and content-based additions.

- The pioneers of an innovation, namely the institution and program affiliates, held the advantage of continuous curriculum improvement. Thus, this helped other schools in the subsequent implementations. However, the front line status of a pioneer also includes dealing with setbacks and disappointments; therefore, a strong focus on the essential elements of the program, namely, the end goal of education improvement and consideration of the ‘hype cycle’, are prerequisites for its growth, maturity, and progress.

**DISCUSSION**

The ‘on-the-fly’ approach showed the development of a technological innovation that was developed specifically from an educational need. The educational field required a solution to overcome its challenges; therefore, the ‘on-the-fly’ educational-driven development to fulfil this need is in stark contrast to the development of a commercial product for the consumer market, which entails production first and implementation later in a curriculum. Developing an innovation within an academic setting allows for the capacity to adapt immediately to any changes in the educational needs. In addition, the technological innovation using the ‘on-the-fly’ approach was created in an educational setting with continuous feedback from its users who are, in fact, content experts of the new technology; therefore, such valuable feedback provides meaningful insights and suggestions towards a further development of the dental trainer.

When using the ‘on-the-fly’ approach, it is important to realise that the ‘development environment’ is always ahead of the ‘production environment’ in which education is organized. When feedback is received in the cyclical process, a time period to implement this feedback to upgrade the innovation to the next level in the ‘production environment’ within a running curriculum needs to be taken in consideration.

When a school decides to be involved actively in education innovation, the team leader/leaders, should form a specific team, based on sound judgment and experience, to guide the innovation and set limits for each step so that the development of the innovation is manageable. The development team should be engaged in both the ‘production environment’ in which the innovation is being used, as well as in the ‘development environment’ in which feedback can be incorporated in the innovation. This double engagement of the program team members offers a cyclical process for idea implementation, setting of production limitations, evaluation of use during tests, and result presentation of its use back to the ‘development environment’ so that the innovation can be upgraded to the next level.

During an innovation within the academic environment, the need for evidence to support that the innovation matches or improves existing educational means should be acknowledged.
The creator of an innovation should maximize the opportunities for education improvement and manage the risks involved to implement the innovation sans evidence. However, evidence is necessary to validate the innovation and generate public support for its use.

Introducing education innovations could be exceedingly difficult, as so nicely phrased by Kalkwarf et al. (2009), ‘It’s easier to move a cemetery than to change a curriculum’. Numerous authors and speakers over the past twenty years have been convinced that this describes the reality of curriculum reform in a contemporary dental school. Indeed, a number of aspects must be considered when introducing an educational technological innovation in a curriculum. A core aspect was the teacher and student involvement at the start of the brainstorming process, as this could generate support for the innovation in the educational institution. However, involvement in the initial DT testing phase seemed to have resulted in a negative bias, which remained present during further development and further testing moments. Concerning the teachers, it appeared that the better and more accessible the interface of the new DT was, the less they experienced a threshold to use the DT as they could more easily enter the content.

Feedback from the use of an education innovation in its nascent stage, namely when the quality is relatively low, could improve and develop further the innovation, supported by the aspiration to improve the quality of education and pioneer a specialty field. However, using an innovation when the quality of the learning environment is already at a higher level makes the implementation and adaptation easier for the stakeholders. Consequently, the advantages derived from the innovation would be missed in the initial stages; however, these benefits could be reaped by later users.

Furthermore, the involvement of a company in the development of an educational product was a challenging factor due to different focuses and interests. Optimally, the world of educational professionals should merge with that of a commercial (technological) company, thereby creating a new world with mutual interests superseding individual gains. However, especially in the trough of disillusionment, this could be a struggle, as both parties would doubtlessly prefer the other to merge into their already existing world.

In addition, constantly monitoring the convergence and coherence of developmental ideas and feedback from stakeholders was important. An educational instrument is likely to generate various opinions and ideas among professionals; to ensure its optimal development, these ideas must be constantly kept in line to maintain focus. Furthermore, we found that management of expectations was an important pillar of stepwise implementation. This was done by information dissemination, surveys, and continuous involvement of professionals in the implementation process, thereby creating a sense of ownership among them. Furthermore, underlining that the DT was still in development, and it was initially a curriculum complement rather than a replacement, may improve user reception. Indubitably, resistance to change must be foreseen; hence, requisite information must be provided to users, particularly highly established teachers and professionals, as they are crucial for the innovation’s reputation.
Conducting research for scientific evidence was necessary to support the use of a technological innovation in education. The willingness of students and the faculty in this process, supported by strong leadership of the management are indispensable. Furthermore, during the research, equity is given to students, and they must not be disadvantaged, particularly during the DT development. Its use requires the approval of the Board of Examinations. Such conditions may result in the experimental design of a study being rather complicated. Importantly, with sufficient evidence confirming the soundness of the dental trainer, further research should focus on the educational value derived from the use of the VRE compared to contemporary teaching methods, in terms of quality and cost amongst others. The first data on this showed positive results. A major advantage of VRE in education innovation is being connected to a database that collects all information on performance and student behaviours during their learning process. Using this information to draw conclusions and provide constructive feedback to students is invaluable.

CONCLUSION

The use of the ‘on-the-fly’ approach for innovation in an academic environment in which scientific evidence is a requirement for support of educational means in a curriculum appeared feasible. Both innovators and users complement each other to progress a new technology into maturity for educational use, dealing with arising issues, justify its use, and increase user acceptance while maintaining focus on the end goal.

Being a pioneer in an education innovation to match pedagogy with contemporary times is possible by using the approach and considering stakeholders’ interests and Gartner’s repetitive ‘hype cycle’. Therefore, to be a pioneer in a certain field of specialty, it is necessary to understand and accept that development precedes evidence.
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