Actionable recommendations for redesigning a pre-clinical dental course: Simulations and students' perceptions of epistemic setting

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Simulations are increasingly used in dental education for developing students' dexterity skills and improving the effectiveness of pre-clinical practice and assessment. The challenge is to embed these technologies into larger instructional frameworks, and to make contemporary teaching and learning practices and environments effective. This study focuses on investigating current simulation-based practices in a pre-clinical laboratory course in a Thai dental school. The purpose is to identify the aspects of the course design that need improvement. Ethnography is used to explore the current situation while an activity-centred analysis and design (ACAD) framework is used to analyse the design of arrangements in the laboratory setting (Goodyear & Carvalho, 2014). This paper reports some results from the students' interviews after the simulation-based laboratory practice. It focuses on epistemic affordances and constraints and shows that these affordances and constraints are not solely embedded in the design of the simulation system, but emerge with the activity from the interaction between the students' personal resources that they bring to the situation and design of the broader learning environment. We illustrate how these results could be used for offering actionable recommendations for improving the course design.

Keywords: professional practice, simulation-based learning, design for learning

Introduction

Simulation-based learning is used to help students learn in close-to-real-world situations. It is implemented in many areas of professional education and training. For example, flight simulators are used to simulate cockpit activities in pilot training (Rosen, 2013), manikins in simulated wards are used instead of real patients in nurse education (Levine, DeMaria Jr, Schwartz, & Sim, 2013), and business simulation games are used in management education (Bell, Kanar, & Kozlowski, 2008). Similarly, dental education is currently experiencing growth in the use of simulation technologies for learning. This includes the use of computer-assisted 3D dental simulations to help dental students develop their manual dexterity skills (Buchanan, 2004; LeBlanc, Urbankova, Hadavi, & Lichtenthal, 2004). These technologies also have the potential to help dental instructors evaluate students' learning more accurately and effectively.

Despite the widespread use of simulation technologies in dental education, there is little research-based evidence to guide:

(1) how dental simulations are best embedded in a complex learning environment,
(2) how to integrate the use of simulation technologies within current pedagogical structures, and
(3) how to modify teaching and learning when necessary in order to get the best results.

This study focuses on creating actionable knowledge for improving designs of simulation-based courses by researching students' practices and experiences within one such course. The data presented in this paper are gathered from students' interviews after a pre-clinical Prosthodontics course that used a computer-assisted 3D simulation system for developing students' practical knowledge and clinical skills. Results from these interviews are used to show how students experienced affordances and constraints of the current design and they inform actionable recommendations for redesigning the dental laboratory course. This paper focuses on illustrating actionable recommendations based on students' perceptions of embodied epistemic experiences of dental practice.

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Background

Dental education and pre-clinical embodied practice

Dental education is complex. Its curriculum often combines both theoretical knowledge and practical skills and uses a range of teaching and learning approaches (Gerzina, McLean, & Fairley, 2005). Dental students have to learn how to integrate theoretical knowledge with the perceptual and motor skills required for safe, effective and efficient practice (Ali, Tredwin, Kay, Slade, & Pooler, 2014; LeBlanc et al., 2004). Clinical skills are among those core competences that students must have when they graduate (Ali et al., 2014; Gerzina et al., 2005). Theoretical knowledge is mostly taught using direct teaching approaches that combine lectures and readings with problem-based tasks and small-group discussions. Manual dexterity skills are developed through practical hands-on activities during pre-clinical laboratories and clinical work. Pre-clinical laboratory courses aim to simulate situations in close-to-real clinical environments, allowing students to experience different situations and explore different aspects, such as diverse patient-dentist positions and various hand-body postures.

Simulation in dental education

Before the availability of manikins or technology-based simulation systems, students learnt manual skills using artificial teeth—known as 'Dentoform' (Figure 1). Students practiced their manual dexterity skills by placing the 'Dentoform' on a flat surface (e.g., a table) and working on the plastic teeth from a 'birds-eye-view' position. However, this posed considerable challenges when students later attempted to perform similar dental work on actual patients within the clinic. With real patients, students had to adopt different hand and body positions from the one practiced in the laboratory, and they often found it very difficult to perform this clinical work proficiently (Ali et al., 2014; Kikuchi, Ikeda, & Araki, 2013; LeBlanc et al., 2004). These challenges evoked the need to improve the quality of dental simulators and to design simulation systems that afford more authentic experience (Kikuchi, Ikeda, & Araki, 2013).

Figure 1: The Hard Gingiva Jaw Model called 'Dentoform'

At present, there are many computer-assisted products for dental education that aim to simulate aspects of the real-world environment, such as the dental unit or the oral cavity. Some of these simulation-based learning devices and systems have been developed with the aim of supporting more realistic practical experiences and also improving feedback and facilitation. There are currently two main kinds of such simulators: 3D augmented reality and haptic systems.

The system used in the observed dental school is a 3D augmented reality simulation, called DentSim® (Figure 2). The dental unit includes four main parts: (1) a manikin head integrated with seven tracking light emitting diodes (LEDs) on the upper and lower jaw; (2) a standard turbine with sixteen tracking LEDs; (3) a dual charge coupled device infrared tracking camera; and (4) a computer-assisted learning environment that includes a monitor and software for tracking the prepared tooth (Buchanan, 2001; Kikuchi et al., 2013).
DentSim® depends on the use of infrared sensors to track the LED light on the manikin and the turbine. The software then records data about hand movement, position and configuration of the tooth being prepared. An image of the prepared tooth is shown on a monitor, with an evaluation button which learners can press if they

want to analyse their work and get augmented feedback. Students can request such evaluation and feedback at any time.

Figure 2: DentSim® learning system with monitor screen showing preparation area and evaluation

Key issues and practical significance

The question that educators encounter is how to integrate new simulation-based technologies like this with existing instructional frameworks, to make learning environments more effective for students. As Schleyer, Thyvalikakath, Spallek, Dziabiak, and Johnson (2012) argue, educators need to know what are the suitable technologies and instructional approaches for their students. Educators need to choose those combinations that are most appropriate for specific learning goals in the learning environment. Schleyer et al (2012) suggest using a holistic methodology for instructional design, considering a wide range of aspects, such as characteristics of the students and properties of the technological devices.

Focusing on dental education and simulation-based practice, most research has set out to compare outcomes from virtual reality-based technology with traditional methods of teaching psychomotor skills (Buchanan, 2004; Kikuchi et al., 2013; LeBlanc et al., 2004; Quinn, Keogh, McDonald, & Hussey, 2003). In general, results indicate more positive outcomes for dental students who use virtual reality: they learn manual skills faster, and benefit from augmented feedback and real-time evaluation (Buchanan, 2004; Kikuchi et al., 2013; LeBlanc et al., 2004). While there are a number of findings on the comparative effectiveness of simulation, dental educators are often more uncertain about instructional approaches that are suitable for their students. In particular, dental educators tend to raise questions about how to embed these devices within the current curriculum (Kikuchi et al., 2013; LeBlanc et al., 2004; Quinn et al., 2003). In other words, there is a gap between the benefits of the technology demonstrated in the literature and knowing how exactly one should combine technology with instructional approaches in a specific setting within the learning environment.

Advances can be made by focusing on two key questions:

- What is actually happening in the current learning environments when students learn in simulation-based laboratories?
- How could we use the above knowledge to decide what changes to make in the curriculum design?

Analysing this complex learning environment more closely is the first step in understanding how this environment functions and could be improved. The focus needs to be on what students are actually doing when they are practicing their manual dexterity using a simulation system. This activity needs to be understood as situated within a complex physical-digital, social and epistemic environment (Carvalho & Freeman, 2016; Goodyear & Carvalho, 2013).

Analytical framework

There are numerous approaches to designing for complex learning, but very few of these approaches integrate both the analysis of complex learning environments and the process of redesign. Many approaches to design for learning assume that designers are creating a new system, not analysing and improving an existing one (Goodyear & Dimitriadis, 2013). The approach to analysis and redesign that we use in this study is called 'Activity Centered Analysis and Design' or ACAD (Figure 3).

The ACAD framework places students' *emergent activity* at the centre of both analysis and design: the most important thing to know about, and to influence, is what students actually do (Goodyear & Carvalho, 2013). Especially in situations where direct supervision of students by teachers is limited, students' activity emerges through a mixture of self-direction and influences from the *physical and social design* of the setting. It is also influenced, though not determined, by the *epistemic design* of tasks that students are given. In short, students' actual learning activity is emergent and physically, socially and epistemically situated.

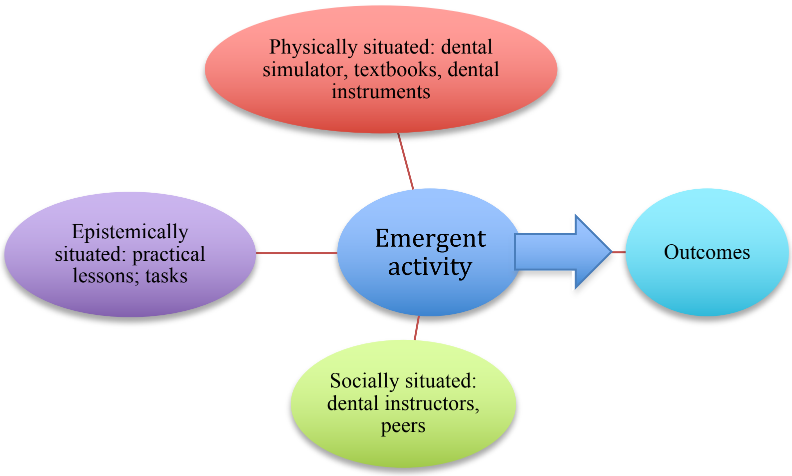

Figure 3: The Activity-Centered Analysis and Design (ACAD) framework, adapted from Carvalho and Freeman (2016)

The ACAD framework is used in cycles of analysis— analysing how the current system works— and redesign— proposing new (versions of) tasks and/or changes to the physical setting and/or ways people work together (Carvalho, Goodyear, & de Laat, 2016; Goodyear & Carvalho, 2013; Goodyear & Dimitriadis, 2013). In other words, the ACAD framework looks at how the epistemic, physical and social become entangled in the emergent activity at 'learntime'. The ACAD framework will periodically, temporarily and artificially separate these three kinds of designable components in order to work out what combinations of changes might be both beneficial and achievable for student learning. Students' perceptions of the simulation-based pre-clinical practice can be used as the first step to generate actionable "knowledge for design" (Carvalho & Goodyear, 2014). This actionable knowledge is approached in a holistic way—connecting physical, social and epistemic aspects of design within an emerging learning activity (Carvalho & Freeman, 2016; Carvalho & Goodyear, 2014; Goodyear & Carvalho, 2013; Markauskaite & Goodyear, 2017).

In this paper, the focus of analysis is on students' perceptions of embodied epistemic experiences of dental practice—in terms of affordances and constraints—after participating in simulated laboratory practice. We also extend the ACAD framework to show that students bring to the learning situation diverse, partly embodied, personal mental resources, such as knowledge, beliefs, skills, habits, emotional qualities, and dispositions. Consequently, new epistemic affordances and constraints emerge as a result of the interactions between what students bring to the situation and what is (epistemically, physically and socially) pre-set for them.

Ideas from the 'Activity-Centered Analysis and Design' (ACAD) framework are used to create actionable knowledge and make suggestions about redesigning the system for better alignment between technology, curriculum and intended outcomes.

Methodology

Setting

In 2013, the dental school used as the site for this research set up a dental simulation centre using the DentSim® system for practicing manual dexterity skills. The faculty believed that introducing the DentSim® system would enable students to improve learning of clinical skills. The Prosthodontic department installed this system, hoping to integrate it within its existing course structure. In addition, the department wanted to introduce self-directed learning as a new competency for dental students. However, problems have arisen from a mismatch between the DentSim® system's intended purpose and the course design.

Participants

Thirteen students enrolled in the Prosthodontics laboratory course volunteered to participate in this study. All participants were third year dental students who had no prior experience using dental simulations and no previous preclinical laboratory courses in prosthodontics.

Procedure

The course lasted 7 weeks; and was divided into 7 periods. Each period had 3 hours of simulation-based practice with the DentSim®. Students' practice in the simulation laboratory was observed and video recorded. The interview sessions were set up at the end of each period to investigate the students' experiences during their practice. Each interview took about 30 minutes and was audio recorded. During these interviews we used episodes from video recorded observations of their pre-clinical practice in the DentSim® lab as prompts and asked questions about those episodes.

Data analysis

Applied thematic analysis (Guest, MacQueen, & Namey, 2011) was used to analyse the interviews and identify categories representing affordances and constraints experienced by the students during simulation-based learning in the DentSim® laboratory. These categories were then grouped into larger themes by using key elements of the ACAD framework (Carvalho & Goodyear, 2014; Goodyear & Carvalho, 2013; Goodyear, Carvalho, & Dohn, 2016). The identified categories and themes represented the relationships between the three aspects of the design—epistemic, physical and social—and students' embodied experiences. In this paper we focus on students' epistemic experiences (i.e. experiences of learning and knowing) and identified epistemic affordances and constraints.

Results: Students' experiences of learning and knowing during simulation-based practice

An epistemic setting is structured by students' experiences or perceptions of learning and knowing during practice (Carvalho et al., 2016). The term 'epistemic affordances' is used to refer to students' perceptions of the enablers that facilitate professional learning and knowing during the simulation-based practice (Gibson, 1979; Markauskaite & Goodyear, 2017); whereas the term 'epistemic constraints' is used to refer to students' perceptions of the limitations or obstacles that restrict the development of their professional knowledge and skills.

Our results show that students' learning within the simulation-based settings cannot be separated from the epistemic affordances and constraints that emerged from interactions between personal resources that students brought to the situation (e.g., knowledge, skills, emotional characteristics) and what was presented within the simulation-based learning environment. This distributed system of epistemic affordances and constraints – distributed between the learners and the environment – was not intentionally designed as such. Rather, it emerged dynamically from students' embodied interactions during the learning activity. The affordances and constraints relied heavily on what students brought to the situation and their embodied experiences.

Epistemic affordances

Students' learning within the simulation-based environment resulted in the students' perceptions of increasing growth from mere declarative (or explicit procedural) knowledge—knowing what needs to be done in order to perform the task ideally—to the knowledge and skills that allowed them to perform the task flexibly and well.

The students mentioned various ways in which they practiced, self-taught, monitored, and evaluated their work and by doing this they gradually gained more experience and understanding of how to perform well and how they could improve their hand and body postures. The students perceived that they developed their practical knowledge and skills, not so much because their learning environment offered special instructional affordances, but because they had possibilities to engage in self-learning processes and develop this embodied knowledge and skills by themselves. These processes reveal examples of emergent embodied epistemic affordances; they rely hugely on students' personal resourcefulness (e.g., knowledge and skills for self-regulation) that they bring to the situation. We found four main categories of such affordances. These were affordances for: learning from experience, self-instruction, self-monitoring and self-evaluation. Each of these categories is described and illustrated in Table 1. Quotes from the students' interviews have been edited for clarity. Text in the brackets explains the meaning of those quotes.

Table 1: Embodied epistemic affordances

Category	Examples from the interviews
Learning from experience Simulation-based laboratory setting creates affordances for development of practical knowledge and skills through repeated practice (e.g., by preparing the same tooth several times and practicing similar clinical skills on multiple teeth).	S1: **"I think it's proper for me** because the first time I always fail about the tooth that I did especially for the occlusal surface and I don't know how to do that. I don't know how to put my hand in the right position but **when I use system like time-by-time and then I know how to change my position.**" [The statement shows that the student did not do well on the first tooth preparation. However, repeated practice with DentSim® helped develop needed knowledge and skills.] S3: "because it's [tooth preparation] very new and we're kind of didn't know which direction we should like do and it's very new experience, new thing, so we didn't catch what is the next step or how and why we have to do like this [how and why to place dental instruments or position hands and body] and what is it for but **once we've done several teeth already it's ok**, understandable." [The statement shows that the student had insufficient understanding and no experience of tooth preparation at the beginning of the session—as she said 'it is very new experience'. However, she developed initial understanding and competence by preparing several teeth and gaining some experience.] S13: "because like **we've already done the posterior and I can adapt knowledge a little bit from the preparation on anterior tooth**." [The statement shows that student's experience preparing one tooth (posterior teeth) helps them gain knowledge and skills needed for preparing a different tooth (anterior teeth).]
Self-instruction Simulation-based laboratory setting creates affordances for self-guided practice. This intentional learning process helps students develop critical professional thinking, independence, and practical knowledge and skills.	S6: "But like now **it's good there's no instructor** looking at us all the time or telling us what to do. So I feel like **I'm doing tooth preparation almost like 95 percent by myself**." [The statement shows that the student can learn by herself. She is learning the preparation by finding out what to do independently without direct guidance from dental instructors.] S12: "And I have to **think critically by myself that it like the proper ways to find out** the way that best for me to use the dental instruments, something like that." [The statement shows that the student is learning to do the preparation independently and deliberately searches for correct ways to use instruments, etc.]
Self-monitoring Simulation-based laboratory setting creates a feeling of authenticity and affordances for developing professional	S6: "you don't get that much practice but **it does make you very careful and I always imagine like this is a real patient. I have to be careful.** I can't go back. I can't buy new teeth. So, it's good that they give us only one tooth because you will be **very careful. We work really hard and concentrate** so that it's like the last tooth."

responsibility and self-control during practical sessions (e.g., awareness, concentration, caution).	[The statement shows the student did her work with careful monitoring of her actions and awareness of the need to avoid mistakes.] S9: "**I'll try to prepare it first on the other area that is not over-preparation yet and I just keep on going and then I reach my limit.** I have to prepare on the region where I say that in the system it said over-prep because it's not smooth." [The statement shows that the student realised what is going on with her work and stopped working on it when there was over-preparation. This shows her awareness, concentration and caution she has in relation to her work.]
Self-evaluation Simulation-based laboratory setting creates for students affordances for assessing their work (e.g., sensing sharpness, observing invisible areas).	S5: "For me, I'm very worried about the sharpness. So, for me if I **use my hand like touch it, I think I can sense the sharpness of my preparation**." [This quote shows the way the student evaluates a tooth preparation by using her hands (i.e., touching a tooth surface to sense sharpness).] S6: "I will **look [at teeth] directly because I feel like there are some blind spots like a point angle that I cannot see** even use a mouth mirror or use the light. And when I **take it [the teeth] out, I will realize that there's a ledge at the point angle everywhere is unsmooth. That's you can see clearly when you take it out**." [This quote shows the way the student self-evaluates her work by using her vision.]

Epistemic constraints

The students also indicated various epistemic constraints that emerged during their pre-clinical practice. Similar to the affordances, a number of these constraints did not directly involve the epistemic, physical or social design of the DentSim® system, but primarily were related to the students' earlier experiences and resources that they brought to the laboratory setting. We found three main categories: lack of initial knowledge, lack of vicarious experience, and reaction to stress (Table 2).

Table 2: Embodied epistemic constraints

Themes	Examples from the interviews
Lack of initial knowledge The students lack of knowledge of how to prepare a tooth correctly before starting the practical session.	S3: "At the beginning, I think it's not... oh! I don't know. **Maybe I didn't understand at the very beginning. I mean like the first period.** [The student means she has not understood how to prepare a tooth structure since the demonstration session.] DI: on 36, right? [The researcher confirmed the student's statement that the term 'the first period' indicates the demonstration session on tooth number 36 where the instructor demonstrated the preparation on a lower left first molar.] [In this statement, the student mentioned her misunderstanding of practical procedure of tooth preparation at the beginning of the practical session and this became the obstacle.] S6: "Like we only learn in one hour or two hours for one preparation so **we don't have that much knowledge and we don't have that much time to read the textbook.** So it's hard to expect that we always have knowledge." [The statement shows that the student did not have enough of the initial knowledge needed to prepare the teeth before using DentSim®]
Lack of vicarious experience Simulation-based laboratory setting does not allow students to see what should be done and how (e.g., how to place a dental	S2: "**I don't really get the clear picture of how the hand should be moved** or the clarifying explanation like how to do it correctly**. I haven't seen like an ideal preparation like the real one** but not in the book or on the computer." [The statement shows that the student did not know how to move her hands and perform the tooth preparation because she did not see an

instrument, how to place their hands).	exemplar of a prepared tooth and preparation procedure before the practical session.] S5: "I think at the first time that I did this. I don't think the instruction is clear because **we only hear the instruction. I didn't like see and I can't imagine what is going on.** So may be like a video of how to pose the angulation of the burr or a demonstration will be very helpful in the first period." [The statement shows that the student had verbal instructions, but lacked vicarious experience and was not able to imagine the preparation process]
Reaction to stress The students experience stress in a simulation-based laboratory which does not allow to learn productively (e.g., in reaction to a negative judgment on their work).	S6: "I feel like if you work someone under stress you don't work it well. Like **I actually feel my hand skills drop if I'm stress."** [The way instructors provide judgments on the student's work affects her skill development – e.g. when the instructor uses a loud voice or is particularly negative.] S6: "Like, I understand this department is like that but some department I feel like I work better in their environment because they don't push us under pressure. Because **when you work under pressure, your hand will be shaking and you try to rush to hand-in in time and then your work is not good as the first hour.**"

Discussion and Conclusions

Relational nature of epistemic affordances and constraints

These insights into the students' perceptions help us understand what kinds of epistemic affordances and constraints they encountered during their dental practice with the DentSim® system in the simulation-based learning environment. These results show that these affordances and constraints were not inherent features of the DentSim® system or of other designed aspects of the learning setting. Rather, they relied on, and emerged from, the interaction with the personal resources that the students brought to the laboratory environment. Further, these affordances and constraints were inseparable from the embodied students' practices with the DentSim® system.

The studied design of the simulation-based learning with the DentSim® system specifically resulted in the epistemic affordances for independent learning by letting the students learn through practice, enabling their agency and activating their self-regulatory processes. However, the overall course design also resulted in some epistemic constraints that restricted students' productive learning. Initial knowledge and vicarious experiences were seen by the students as preconditions for their successful learning through practice and they felt they lacked this.

These emerging epistemic affordances and constraints give us an insight into the process through which the students develop clinical skills. While authentic embodied practice is critical, the success of this practice is inseparable from students' personal resourcefulness for regulating their learning and their initial knowledge of how to perform clinical procedures. The emerging relationships between the students' resourcefulness and features of their learning environments help us see the problematic areas and offer actionable recommendations for re-design. For example, lack of initial knowledge and vicarious experience could be alleviated by improving students' preparation for laboratory practice or offering additional instructional resources that students could use during their practice. Further, the productivity of their learning through practice could be improved by designing instructional scaffolds that help students develop their self-regulation and other meta-cognitive skills.

Markauskaite and Goodyear (2017) argue:

> Understanding the instructional and psychological principles underlying the effectiveness of a tool or technique may allow one to adapt them flexibly to different situations. (Markauskaite & Goodyear, 2017, p. 90)

Similarly, dental educators could benefit from better understanding of what makes various simulation-based technologies and instructional approaches productive. This study further highlights that educators need to know what personal resources their students bring to a particular learning situation and what kinds of affordances and constraints emerge. This knowledge could help them better prepare students for pre-clinical laboratory practice and adjust the existing design of the simulation-based learning environments and courses to match students' needs: allowing for greater learning to take place.

Actionable recommendations for improving learning through embodied practice: some illustrations

Greater understanding of the emerging relationships between the students' resourcefulness and features of their learning environments helps us see the emerging benefits and problematic areas in the current design of the simulation-based learning and offer some actionable recommendations for course re-design.

Firstly, the students indicated that one of the main affordances of DentSim® is a possibility to gain experience and develop knowledge and skills through physically situated, independent and embodied practice. However, the students often needed to draw on various mechanisms for autonomous, self-regulated learning in order to learn via practice successfully. These independent learning mechanisms were not scaffolded by the course (epistemic) design and relied on the students' personal resourcefulness. This finding suggests that the productivity of independent learning for all learners, including those who don't have sufficient independent learning skills, could be enhanced by embedding instructional scaffolds for self-regulation into the design of instructional materials. For example, this could be done by explicitly asking questions that help students monitor the quality of their work or by pointing out typical 'blind spots' and making practical suggestions about how to avoid them. While we did not explore the design of social aspects of the learning environment (e.g., peer-tutoring and peer-feedback), social design could also be used to help enhance students' learning through practice.

Secondly, information about the epistemic constraints needs to be taken into consideration. The evidence about the students' stress invites the instructors to consider new approaches for feedback and evaluation. For example, they could consider changing the evaluation process in a way that reduces students' fear of negative feedback and failure. The students' lack of initial knowledge and vicarious experience could be addressed by offering learning resources that the students could use before practical sessions, and by adding instructor-led demonstrations to the sessions. In particular, the demonstrations could help students see the way professionals place the dental instruments in the oral cavity and ask questions; while later the instructors could provide focused one-to-one guidance for individual students when needed.

To summarise, we can use the results about students' experiences of epistemic affordances and constrains for developing actionable knowledge for course re-design. These experiences show the emerging relationships between the students' learning and knowing processes and their learning environment. The results could be used by the dental educators who work in the simulation-based laboratory to improve the design of the course in order to maximize learning benefits in the existing laboratory environment. Finally, the approach could be used to improve dental teaching knowledge in this area more generally.

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