Utilising activity theory as a framework to evaluate the implementation of a virtual simulation educational tool

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Abstract: Virtual simulation is recognised as an important educational tool, providing students with access to learning experiences that that may be difficult to achieve by other mechanisms. Using an activity theory framework and drawing upon survey data, this research examined the implementation of a virtual radiography (x-ray) simulation tool into an undergraduate course. Students report that the technology is easy to use and they benefit by being able to repeat activities in a safe (non-radiation) environment. Having used the simulation students reported an increase in technical and cognitive skills. This study also showed that students value using the technology both as an individual and collaborative learning activity. In addition, students identified that they prefer to use the technology as a teacher-led rather than a self-directed activity. Educators need to be mindful of both the range of learning outcomes that simulation affords and also the learning preferences of student groups.

Introduction

Simulation is increasingly being adopted within the undergraduate health curriculum to supplement and enhance pre-clinical learning opportunities for students. The impetus for using simulation in Australian health care education is the large increase in undergraduate student numbers coupled with pressure to increase productivity within hospitals (Bridge et al., 2016; Weller, Nestel, Marshall, Brooks, & Conn, 2012). This means that within the clinical environment of the hospital student access to patients is reduced.

Simulation of the clinical environment can contribute to or expand opportunities for students to gain the skills necessary for clinical practice. There are multiple modes of simulation currently utilised within the health curriculum including full and part body mannequins, simulated patients or 'patient actors', and computer based simulations (Weller et al., 2012). In recent years, the use of computer-based simulation within the undergraduate health curriculum has been actively supported. For example, from 2011-2013, Health Workforce Australia, committed $90.33 million to the Simulated Learning Environments program (Health Workforce Australia, nd). This program sought to reform clinical training by enabling the adoption of simulation in the health sector and through capital and current investment expanding the capacity for simulated learning as part of clinical training. Between 2011 and 2012, the number of simulation education hours, as part of clinical training, through the Simulated Learning Environments program increased by 115%. Health Workforce Australia funded simulation projects include virtual dental, virtual endoscopy and computed tomography simulators designed to assist students develop essential technical skills before they attempt procedures on patients (Health Workforce Australia, nd). Multi-user simulation platforms such as Second Life® are also incorporated into healthcare curriculum to develop communication (James, Maude, Sim, & McDonald, 2012) and decision making skills (McCallum, Ness, & Price, 2011). When the learner actively engages with the technology, virtual simulation acts as an intellectual partner becoming a cognitive tool which empowers the learner to think more meaningfully (Jonassen, Howland, Marra, & Crismond, 2008). Virtual simulation is a tool that mediates learning offering the potential to develop both technical and cognitive skills.

Virtual simulation, mediated learning and activity system

Given the important role of virtual simulation within healthcare curriculum, Vygotsky's (1981) model of learning mediated by tools is a theoretical framework useful for examining the implementation of virtual simulation within the curriculum. This framework has resonance as virtual simulation tools are examples of external tools that support and enhance learning (Jonassen et al., 2008). Learning, as an act mediated by tools, is commonly expressed in Vygotsky's triadic representation (Engestrom, 2001). The Vygotskian model of mediated learning has three central elements – subject, tool and object (Figure 1).

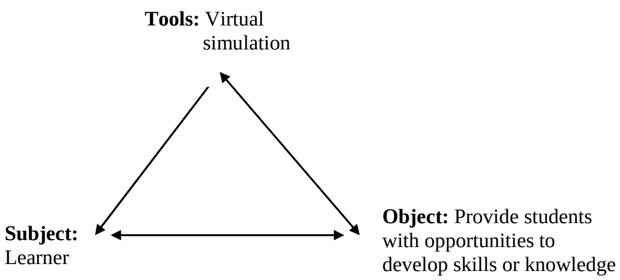


Figure 1 Common representation of Vygotskian model of the mediated learning act

In the Vygotskian triad, the *subject* is defined as the learner. The learner is viewed as an active agent purposefully utilising mediating tools to achieve their learning goal (Kaptelinin & Nardi, 2006; Vygotsky, 1981). *Tools* are utilised by the learner to support the learning process. Tools may be external or internal. External tools are material tools such as simulation tools or platforms adopted within the curriculum. Internal tools include processes utilised by the individual to support knowledge construction, such as mnemonic techniques and schemas of objects or event (Merriam & Cafarella, 1999). Both external and internal tools act as aids, or cognitive tools, enabling knowledge construction (Jonassen et al. 2008). The *object* is the final component of the Vygotskian triad and relates to the goal of the learning activity (Kaptelinin & Nardi, 2006). For example, from an academic perspective, the goal of the learning activity may be to provide students with opportunities to develop their knowledge or technical skills.

The Vygotskian model, focussed on the action of the individual, is regarded as first generation activity theory. Engeström (2001) argued that the actions of individuals cannot be understood without understanding the activity of the whole system. Vygotsky's original model was graphically expanded into a collective activity system model. This collective activity system, regarded as second generation activity theory (Engestrom, 2001) is depicted in Figure 2 as an activity system for students enrolled in a university course utilising virtual simulation as a mediating tool. This is represented in the uppermost sub-triangle.

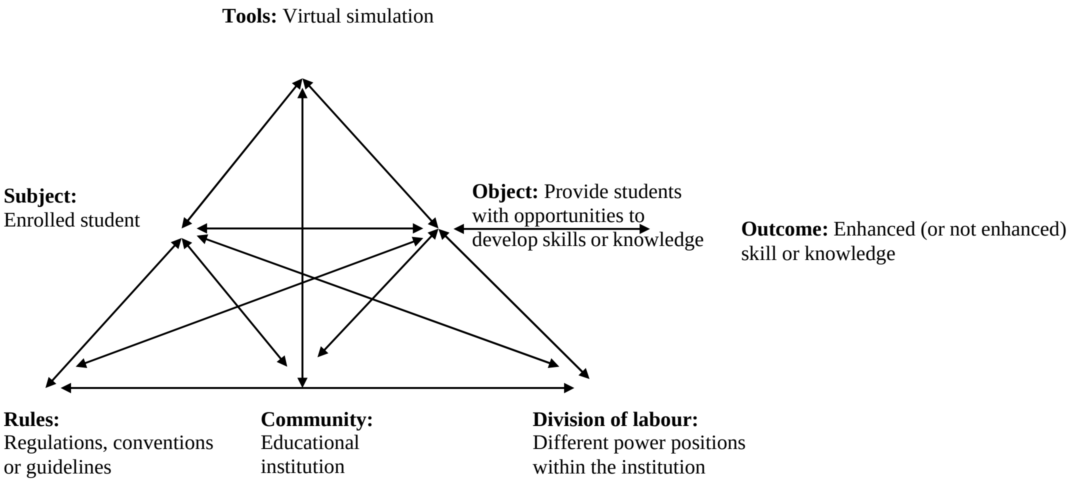


Figure 2 Representation of Activity System where virtual simulation is used to provide students with opportunities to develop skills or knowledge.

The second-generation activity theory model (Figure 2) expands beyond the upper most sub-triangle and recognises that subjects, objects and tools of activity, operate within a cultural historic system of community, rules and divisions of labour. *Community* refers to the wider community and, for example, when the activity system is focussed on learning, community includes educational institutions and class room of instruction (Engestrom, 1994). Learning within the class room can involve both individual and shared knowledge construction. As an individual activity, the learner engages with the technology to construct meaningful understanding (Grabowski, 2004). Learning with simulation technology may also be a shared knowledge construction activity. Through discussion learners can seek out and exchange opinions and ideas with others (Jonassen et al., 2008; Wenger, McDermott, & Snyder, 2002). Through this shared process, knowledge construction expands beyond the individual and is conceptualised as an active process of negotiating shared meaning amongst learners (Jonassen et al., 2008). Learning with simulation technology may incorporate both individual and shared knowledge construction.

Within an activity system, *rules* refer to given or negotiated guidelines, directives or regulations that influence the activity system (Kaptelinin & Nardi, 2006). Rules act as a source of tension as they can afford or constrain what is allowed within the activity system. For example, with virtual simulation, university IT requirements can constrain activity. James et al. (2012) investigated the use of Second Life® to develop communication skills and interdisciplinary knowledge amongst undergraduate health students and concluded that IT problems beleaguered the study. The *division of labour* refers to the social reality of participants in the activity system. Divisions of labour act as a source of tension within an activity system with hierarchies of power creating different positions for different participants within the system (Engestrom, 2001). Within education, there can be for example, a tension between the role of teacher and student in learning activities. For example, whether learning activities utilising a simulation tool are teacher-led or student-led activities. Engeström's activity system model also introduced an outcome of activity. The *outcome* of activity refers to the intended or unintended implications of activity (Kaptelinin & Nardi, 2006). The outcome of a learning activity system mediated by simulation tool may be, for example, enhanced (or not enhanced) skills or knowledge of the students (Figure 2).

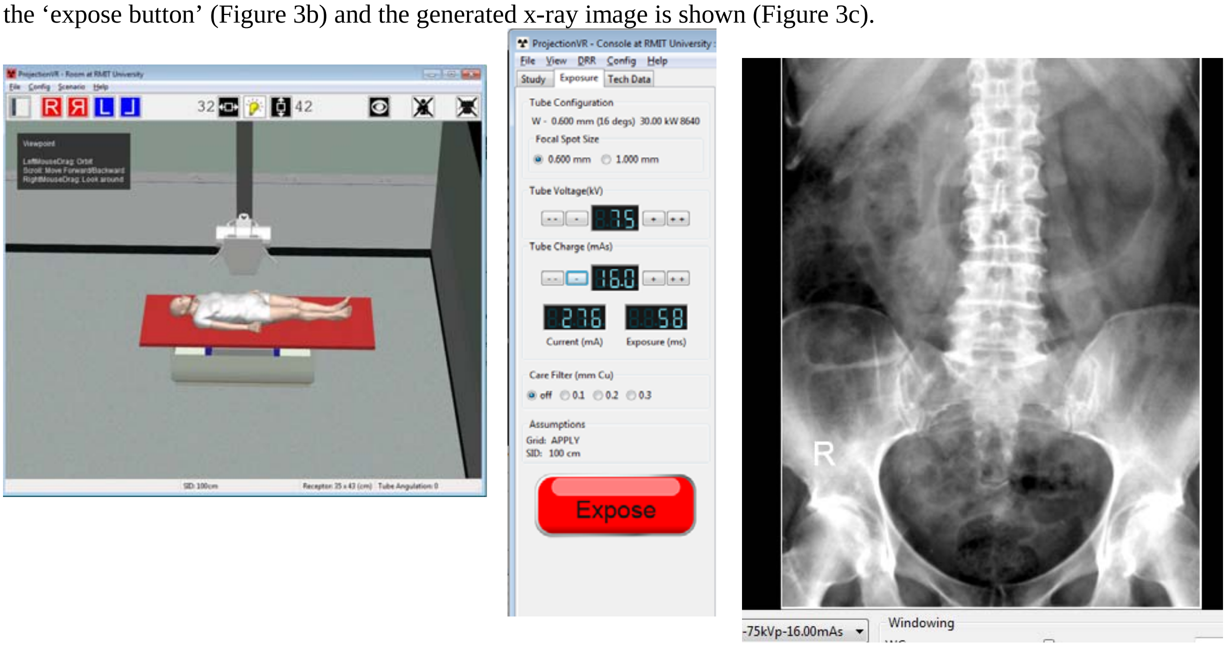
The Study

The context for the study

All radiographers are expected to have excellent radiographic positioning and image evaluation skills. As diagnostic radiography involves the use of ionising radiation, student use of radiography equipment is tightly controlled in laboratories at university and in clinical placements. This limits student ability to practice and learn fundamental components of radiographic practice. Mason (2006) asserts the two primary stressors of radiography students during clinical placement are 'fear of making a mistake *I* repeat' and 'feeling unprepared/ inexperienced'. Virtual simulation, where radiographic images are generated without the use of ionising radiation, allows students to develop their understanding and practise their skills, in a safe pre-clinical learning environment. Within radiation therapy programmes, the introduction of virtual simulations, such as VERT^{TM} , has successfully allowed students to practice technical skills and has led to increased student confidence (Bridge, Appleyard, Ward, Philips, & Beavis, 2007; Bridge et al., 2016; Green & Appleyard, 2011) and students better prepared for clinical placement Students appreciate the safe learning environment that VERT^{TM} provides, allowing them to develop their skills without endangering a “patient” (Bridge et al., 2007; Bridge et al., 2016; Green & Appleyard, 2011), the ability to make and learn from their mistakes (Bridge et al., 2007) and undertaking procedures with less ‘time pressure’ than occurs in clinical practice (Bridge et al., 2007; Bridge et al., 2016). Virtual radiography simulation would offer the same benefits to diagnostic radiography students, who similarly use ionising radiation and operate under time pressures in clinical practice. Whilst the use of virtual simulation is well established in radiation therapy, its use in diagnostic radiography is not.

Simulation software

Projection VR^{TM} is one of three simulation software within Virtual Radiography^{TM} (Shaderware, UK). Projection VR^{TM} simulates diagnostic radiography examinations. There are two windows that need to be opened to use the Projection VR^{TM}, the X-ray Room (Figure 3a) and the X-ray console, where the x-ray exposure is made by pressing the ‘expose button’ (Figure 3b) and the generated x-ray image is shown (Figure 3c).



a) X-ray room

b)X-ray Console – exposure is made

c) X-ray Console – image generated

Figure 3 Projection VR^{TM} images of X-Ray Room (a) and X-ray Console (b, c)

Weller et al. (2012) advocates that for maximal effectiveness, simulation must be integrated into the curriculum. In the context of this study, Projection VR^{TM} was integrated into the laboratory component of an undergraduate radiography course. This meant that all students were scheduled to participate in Projection VR^{TM} activities as one rotation within their scheduled weekly laboratory throughout the semester.

The aim and research questions

The aim of this study was to evaluate the implementation of software simulation into the curriculum. When introducing a new technology it is important to get feedback on the tool and its usefulness to the users. The representation of activity systems as complex interacting activity-based systems, considers participants and tools or resources present in an activity, as well as the context within which the activity occurs. The benefit of using an activity system framework, according to Issroff & Scanlon (2002), is that it forces consideration of a range of factors which impact on the use of technology in higher education. This approach supports getting user feedback that extends beyond student reaction or satisfaction with the tool (Weller et al., 2012) to include a broader range of factors in the evaluation. The component of the activity system examined in this study and research questions are listed below:

1) Student -Tool (Projection VR^{TM})
   Research questions:
   a. Did students find the software easy to use?
   b. Did they like using the tool?
   c. Did technical problems make using the tool difficult for students?

Licencing requirements (acts a rule within the activity system) meant that students could only access the simulation in one laboratory at the university.

2) Rule (Licencing requirements) – Student – Tool
   Research question:
   a. Did students use the tool outside of their scheduled laboratory time?

The introduction of virtual simulation into the laboratory aimed to provide students with additional opportunities to develop their radiographic skills and knowledge.

3) Student – Tool – Outcome
   Research question:
   a. Did students report enhanced skill or knowledge? If so what were they?

Projection VR^{TM} activities were undertaken by students both as individual and as small group activities.

4) Student – Community – Tool
   Research question:
   a. Did students prefer to use the tool as an individual or collaborative learning activity?

Projection VR^{TM} activities were undertaken both teacher- and student-led activities. Within the activity system, this represents the division of labour.

5) Division of Labour – Student – Tool
   Research question
   a. Did students prefer to use the tool as a teacher-led or student-led learning activity?

Methodology

Survey methodology was the primary data sources for the study. All students enrolled in the course, in which Projection VR^{TM} was added within the laboratory component were invited to participate at the completion of semester teaching. All survey feedback was anonymous and provided voluntarily via an online survey (Qualtrics). The survey questions included Likert-style and open question formats. The survey data were entered into SPSS 21.0® and descriptive and inferential statistics were used for analysis. Cross tabulations were performed using learning preferences and self-reported learning outcomes to determine if relationships existed. Differences between groups were examined using chi-square analysis and Fisher’s exact test. Ethical approval for data collection was provided by the university.

Results and discussion

Responses were received from 84 out of 86 students enrolled in the course. Not all students responded to all questions. The number and percentage of students responding to a given question is provided throughout the results section of this paper. With regards to the gender and age characteristics of the responding students, the majority of students were female (70%). This reflects gender data for Australian Medical Radiation Practitioners where females account for 67.6% (Australian Institute of Health and Welfare, 2013) All age groups were represented, with over 50% being 22 years of age or greater (not direct high school leaver) students.

Student -Tool (Projection VR^{TM})

Student perceptions on using Projection VR^{TM} are presented in Table 1.

Table 1 Student perceptions on using Projection VR^{TM} (n=82)

Question	Strongly agree	Agree	Neither agree or disagree	Dis-agree	Strongly disagree	Total Number	Mean
I liked using Projection VR^{TM}	26	39	11	6	0	82	1.96
Projection VR^{TM} is easy to use	13	55	9	5	0	82	2.07
Technical problems made using Projection VR^{TM} difficult	3	14	24	36	5	82	3.32

Overall students liked using the simulation software and were positive in terms of its ease of use. Comments included "It is easy to use gives us a better understanding" and "easy to use". Students also appreciated the virtual nature of the radiation exposure, e.g. "Being able to repeat exposures without worrying about patient dose" and "I can take as many projections without hurting anyone". Technical difficulties were reported by 17 (out of 82) students. Students identified that there was "learning curve" and the simulation was "difficult to learn at first". The most frequently identified issue by students was getting used to the computer control keys to move equipment. This was described as "frustrating", "time consuming" and "took a lot of practise". Some students also experienced difficulty moving the patient or specific items of equipment such as the x-ray table.

Rule (Licencing requirements) – Student – Tool

Students were asked if they used Projection VR^{TM} outside of their scheduled laboratory time. Whilst the majority of students (83%, n=62) agreed that they could access the simulation outside of their scheduled laboratory, 90% (n= 74) of students reported that they only used this software during their scheduled laboratory. Low uptake of use outside of the scheduled laboratory may be influenced both by the small number (7) of licences available and that the software was only available in only one on-campus laboratory. In written comments to the survey question "What would you change to improve using Projection VR^{TM} as part of the labs" students indicated that increasing the number of licences and making the software available outside of the laboratory e.g. on library computers and for home use would improve student use. Remote access to university educational resources is viewed positively by students providing them with greater flexibility about when they engage with educational resources and allowing them to work at their own pace (MacDonald-Hill & Warren-Forward, 2015). Students in this study identified that access to the simulation, from home or the university library would be a beneficial change e.g. "would be an amazing tool for revision at home". Increasing the number and type of licence would provide greater flexibility in when, where and for how long students access the simulation. This change in licencing would benefit students and is currently being implemented.

Student – Tool – Outcome

Projection VR^{TM} offers students opportunities to develop their skills and confidence through repeated generation of images, without using ionising radiation. Students were asked how using Projection VR^{TM} may have affected aspects of their learning and confidence. The number (percent) of students who Strongly Agree or Agreed with each of the listed statements that relate to learning outcomes from using Projection VR™ are shown in Table 2.

Table 2 Student perceptions on Projection VR™ as a learning tool (N=82)

Question **Using Projection VR™**	Agree n (%)	**Question** **Using Projection VR™**	Agree n (%)
Enhanced my routine procedure for setting up radiographic examinations	61 (74)	Helped me become more fluent or systematic in a radiographic examination e.g. not repeating steps	55 (67)
Encouraged me to think more about radiographic procedures	71 (87)	Encouraged me to solve problems	70 (85)
Had a positive effect on my ability to set up a radiographic examination	64 (78)	Had a positive effect on my confidence level in setting up radiographic examinations	61 (74)
Allowed me to quickly see images and understand if changes needed to be made	77 (94)	Had a positive effect on my confidence level in evaluating radiographic images	68 (83)
Enhanced my image evaluation skills	71 (87)	Had a positive effect on my ability to self-evaluate when I set up radiographic examinations	72 (88)
Had a positive effect on my ability to evaluate radiographic images	70 (85)	Had a positive effect on my ability to self-evaluate when I evaluate radiographic images	69 (84)
Helped me learn as I was able to repeat activities until I was satisfied with the results	78 (95)	Encouraged me to think more about evaluating radiographic images	75 (91)

Overall students perceive that Projection VR™ is a useful educational tool. Its primary strengths lie in the ability to see images quickly and determine if changes were required and the ability to repeat images until satisfied. Students identified that this simulation enhanced their image evaluation, problem solving and self-evaluation skills. To a lesser extent student perceive Projection VR™ enhancing their ability to set-up radiographic projections. Likewise students reported Projection VR™ had a greater impact on their confidence level in evaluating images compared to their confidence level in setting up radiographic examinations.

Overall the results from student feedback demonstrate that the introduction of Projection VR™ into the laboratory has been a positive addition to the course. Students attribute increase in confidence level in setting up radiographic procedures and evaluating radiographic images. Increasing student confidence level in these fundamental components of radiography before clinical placement may make the transition from university to clinical practice less stressful for students (Mason, 2006).

Students report that having participated in Projection VR™ simulations increased their ability to set up radiographic procedures and evaluate radiographic images, fundamental capabilities for the practice of diagnostic radiography (Australian Institute of Radiography, 2013; Medical Radiation Practice Board Australia, 2013) With these capabilities enhanced in the pre-clinical environment, this should allow better utilisation of student time in the clinical setting to concentrate on those skills and experiences that can only be obtained in that setting. For example Bridge et al. (2016) identified that the pre-clinical use of virtual simulation in radiation therapy improved student technical skills allowing students to concentrate more on patient interaction skills whilst on clinical placement.

Students also attributed participating in Projection VR™ activities to having a positive impact on their thinking, self-evaluation skills and involvement in problem solving. This is an important finding, suggesting that purposeful implementation of this educational technology is empowering students to critically reflect on their work. Application of critical and reflective thinking is a key attribute of the Australian accredited medical radiation practitioner (Australian Institute of Radiography, 2013; Medical Radiation Practice Board Australia, 2013). This means that careful implementation of this technology within undergraduate programmes can contribute to multiple professional standards by not only developing required radiographic skills (Domain 5a, Standard 1) but also developing critical and reflective thinking required to resolve clinical challenges (Domain 3, Standard 1) (Medical Radiation Practice Board Australia, 2013).

Student – Community – Tool

Projection VR™ activities were undertaken by students both as individual and as small group activities. Student preference is reported in Table 3.

Table 3 Student preferences for learning with Projection VR™ (n=82)

Question I learn best with Projection VR™ when it is:	Number (%)
An individual activity (I used Projection VR™ on my own)	19 (23)
A shared activity (I used Projection VR™ with 1 or 2 other students)	30 (37)
Both / either an individual or shared learning activity	33 (40)

Students identify that they learn best with Projection VR™ when learning activities are either focused as individual or as shared learning activities. Cross tabulations were performed to determine if learning preference for individual or shared activity was associated with perceived learning outcomes (Table 2 statements). Difference was not statistically significant ($p>.05$) for any statement.

In the laboratory sessions, when students worked independently or small groups they were observed to discuss their generated image with a student sitting next to them. It was also observed that students who had greater familiarity with the software helped student sitting near them. Collaboration between students occurred both during independent and small group activities and helped students work with the technology as well as develop their knowledge, skills and problem solving abilities (Table 2).

Division of Labour – Student – Tool

Projection VR™ activities were undertaken both as teacher-led and student-led activities. Student preference is reported in Table 4.

Table 4 Student preferences for learning with Projection VR™ (n=82)

Question I learn best with Projection VR™ when it is:	Number (%)
A teacher-directed learning activity	43 (52)
A self-directed learning activity	1 (1)
Both / either a teacher-directed or self –directed learning activity	38 (46)

Only one student identified that they learn best with Projection VR™ solely as a self-directed learning activity. Most students identified a preference for learning with Projection VR as a teacher-directed activity or they indicated that they had no preference for who directed the learning activity. Cross tabulations were performed to determine if learning preference for teacher-led or student-led activity was associated with perceived learning outcomes (Table 2 statements). Difference was not statistically significant ($p>.05$) for any statements.

Preference for teacher-led activity may be associated with the previously mentioned learning curve associated with using the software. It may also reflect the nature of the teacher-led activities, where, before generating an image, students were asked to predict what they would expect to see on their image. This approach was adopted to support student active engagement with each activity and promote critical thinking as students are required to consciously pause before they implemented their next action (Rodgers, 2002). When technology is purposefully used to support knowledge construction, it acts as a cognitive tool (Jonassen et al., 2008). This means the tool act as an intellectual partner with the learner empowering the student to think more meaningful as they test their hypothesis. This approach may contribute to the findings (Table 2) that student report that they "think more about" radiographic positioning and image evaluation having used the simulation tool.

In addition, almost half the students indicated that they learn equally well with this tool when it is teacher-led or self-directed. This suggests that with change in licencing proposed for 2016, greater licence numbers and flexibility with where students can access the simulation, greater use of the simulation outside of scheduled laboratory hours may occur. This will then provide students with greater opportunities to develop their technical skills, thinking and self-evaluation skills, and their confidence. With these capabilities enhanced in the pre-clinical environment, this should allow better utilisation of student time in the clinical setting to concentrate on those skills and experiences that can only be obtained in that setting. A finding associated with the use of virtual simulation VERT™ in the undergraduate radiation therapy curriculum (Bridge et al., 2007; Bridge et al., 2016).

Conclusion

By using an activity theory framework to evaluate the implementation of a new simulation tool, multiple factors have been investigated. This study has demonstrated that students have found the simulation easy to use, they like using it and overall the introduction of the simulation was not associated with many technical difficulties. Students identified that through using this simulation their radiographic skills, as well as their problem solving, thinking and evaluation skills have been enhanced. Students prefer to use the simulation both as an individual and as a shared learning activity. A preference was shown by students to use the simulation as a teacher-led activity. Constraints identified within the activity system include the limited number of simulation software licences and physical constraint as to where the simulation could be accessed. These identified constraints in student use of the simulation are being addressed for the 2016 academic year.

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