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An activity theory approach to analysing student learning of human anatomy using a 3D-printed model and a digital resource

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Abstract

Introduction The availability of different tools for teaching and learning has made it challenging for educators to determine which tools are more effective and appropriate for helping students achieve learning outcomes. This is particularly evident in teaching human anatomy, where a range of modalities is used to complement cadaveric dissection. Despite the positive reception of these tools, their impact on learning outcomes remains uncertain. To address this issue, we utilise the Activity Theory Framework to analyse students' interaction with two tools – a 3D-printed (3DP) model and a digital resource (DR) – to answer two clinical questions relating to the lower spine.

Method This study took place in a graduate medical school in Singapore. Forty-six students voluntarily signed up for the session. They were grouped in small teams of between 4 and 6 students, and interactions were video recorded. Using a cross-over design, five groups answered a clinical scenario using a 3DP lumbar spine model, while the other five groups used the DR. The teams then swapped the 3DP with the DR and vice versa to answer a second clinical scenario of similar difficulty.

Results There was no significant performance difference in terms of scores. Using a case study approach, we found that students engaged in more authentic discussions using the 3DP compared to the DR. Despite having access to the system early in the semester, students appeared unfamiliar with using the DR, struggling initially to navigate the software. We found the 3DP model encouraged collaborative discussion as students could physically use it as a tool for discussion by pointing and manipulating the different components in three dimensions, which could not be done with the DR as it operates on a two-dimensional screen.

Conclusion This study used activity theory to understand the impact of two educational tools on learning. Activity theory allowed a better understanding of tools' dynamics in learning when looking beyond score performance. We found that 3DP better encouraged collaboration among students than DR. Educators must consider the ease of use of the learning tools when designing activities so that learners will utilise the system's affordances.

keywords Digital learning resource, Anatomy education, Cultural-historical activity theory (CHAT), 3D-printing, Anatomy education, Fused deposition modelling (FDM), Mixed-method research, Case study

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Introduction

Over the past 20 years, various innovative learning approaches and technologies [1–5] have been used for teaching and learning in medical education domain. These innovative learning technologies enable a multimodal approach [6, 7] to learning by complementing traditional cadaveric dissection. Amongst these, three-dimensional printing (3DP) has been used for training in ophthalmology [8], radiology [9], pediatrics [4], and neurosurgery [10]. Digital resources such as Primal Pictures (PP) [11] have enabled learners to access high-resolution and interactive anatomical images, and virtual reality [12, 13] and dissection Table [14] are increasingly being used to learn and teach human anatomy. These technologies are not meant to replace traditional cadaveric dissection [15, 16], but to complement the learning experience [17] [18, 19]. Previous studies have shown that this multimodal approach can accommodate different learning styles [6], enhance student engagement [20], and prepare students to handle more complex clinical challenges [21] in the future.

Traditional two-dimensional (2D) teaching approaches (e.g., textbooks and images) fall short when teaching the complexities of spatial awareness in learning human anatomy. Spatial awareness is the ability to spatially manipulate mental concepts of objects, which is critical [22–24] in medical education and clinical practice. This is where technologies such as 3DP, digital resources (DR) and visualisation tools like PP and Virtual Reality (VR) can provide learners with a tangible manner for easily manipulating the anatomical structures of interest to improve their understanding [1, 5].

Despite these promising advances, there is still a gap in understanding the impact of these learning technologies on student outcomes. For example, how these technologies integrate with and influence traditional learning modalities is still particularly unclear. To improve best practices in medical education, researchers must understand how these tools are used in human anatomy education.

Purpose of the study

This study aims to understand how students learn human anatomy using 3DP and DR. To understand the learning process, students were given two learning activities to complete using a 3DP and a DR. We will use Activity Theory [25] as a framework to analyse collaborative interactions and the social dynamics of 3DP and DR in learning for two case studies. The findings will help develop effective educational strategies that align with contemporary pedagogical needs.

Theoretical framework

Activity theory

Cultural-Historical Activity Theory (CHAT) is a theoretical framework grounded in sociocultural theory [26] used to analyse how people interact with their environments [25] and each other within a complex system of activities. It is well-established in the field of education [27]. The framework is flexible as it views contradictions within and between activity systems as sources of change and development. Identifying and analysing these contradictions can lead to a better understanding of salient challenges and tensions in educational settings, guiding innovation and improvement [28]. Activity theory comprises subject, object, outcome, tools, rules, community, and division of labour. These components change depending on the analysed activity system [29] (Fig. 1).

CHAT has been used in medical education [30] to study its cultural complexity, understand how postgraduate residents perform discharge planning [31], OSCE assessment [32], and understand student learning goals in clinical education [33].

Activity theory comprises individual agency and community-level processes. Combined, an individual's actions can be analysed in a sociocultural context. For example, in a medical education classroom, the subject within an activity system may refer to the individual medical students or groups engaged in an activity driven by different motives and outcomes. The object refers to a clinical scenario given in class, while the outcome of the activity would be to solve the clinical scenario. This results in the medical students (subject) interacting with the clinical scenario (object) and using different learning tools to solve the clinical scenario (outcome). Rules of the system are the norms, conventions, and regulations that govern interactions within the community, which is the group of individuals sharing the same object for the same purpose, providing social context. Within the community, the organisation of tasks, responsibilities, and authority is called the division of labour.

Methods

Setting and participants

The study occurred at a graduate medical school in Singapore. Students were enrolled in the Doctor of Medicine (MD) Program and have completed their first basic degree. The school adopts a team-based learning [34] (TBL) approach where students work together as a team of six throughout their entire course of study. The TBL approach encourages discussion, and students only submit one team answer. Each cohort of students is no larger than 78 students, and the program lasts 4-years with a one-year pre-clerkship where the basic sciences are taught, a one-year Clerkship followed by a Research and

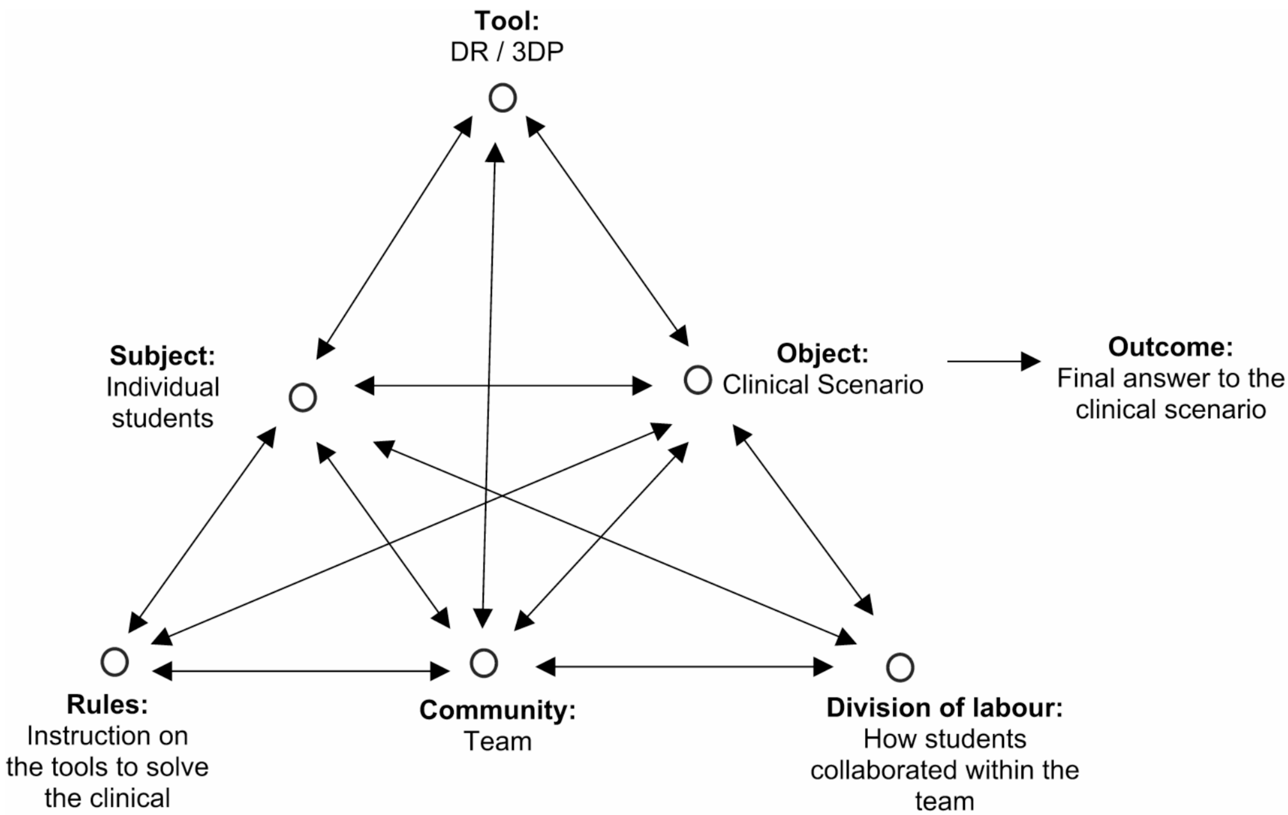

Fig. 1 Cultural-historical activity theory framework within medical education

Scholarship year, and the final year of Advanced Clinical Rotations.

Participants were recruited from Year 1, Semester 1 of the pre-clerkship program for the "Foundations of Patient Care 1" course. This course integrates the disciplines of biochemistry, cell biology, genetics, embryology, anatomy, radiology, microanatomy, physiology, and neurosciences. Forty-six students voluntarily stayed back after a tutorial to participate in the optional one-hour session led by the Spine Anatomy course instructor (RS).

Each team had to solve two clinical scenarios of similar difficulty. Using a 2×2 cross-over design, five teams solved the clinical scenario using a customised 3D-printed lumbar spine model, and the other five teams used a licensed digital resource (DR) called Primal Pictures [35] on their own devices. After 15 min, participants swapped the 3D-printed model for the DR and vice versa to solve the second clinical scenario. Students were allowed to use additional resources when answering the clinical questions.

3D-printed model

The 3D-printed lower spine model was custom-made based on the course instructor's requirements. It was printed in-house using fused deposition modelling (FDM), a commonly used and cost-effective 3D printing technique. The model was customised so that the lamina between L3 and L5 could be removed allowing students to access the "nerve roots." Fig. 2 shows an image of the customised 3D-printed model.

Digital learning resource

At the start of the academic year, students were given access to a licensed digital resource, Primal Pictures [35], accessed on a browser or tablet (Fig. 3). Primal Pictures is a well-established anatomy resource that offers detailed and interactive 3D anatomical models of the human body, including animation, clinical videos, dissection slides, and diagnostic images for learning.

Video recording

Six teams were randomly selected so that the discussion during the tutorial session could be recorded (Team 2, Team 3, Team 6, Team 10, Team 11, Team 12). The authors reviewed all the video recordings at least once. The classroom layout caused substantial crosstalk, making video reviewing challenging. After several rounds of internal discussion, the authors identified two video recordings with the best quality for further analysis as a case study using the research framework.

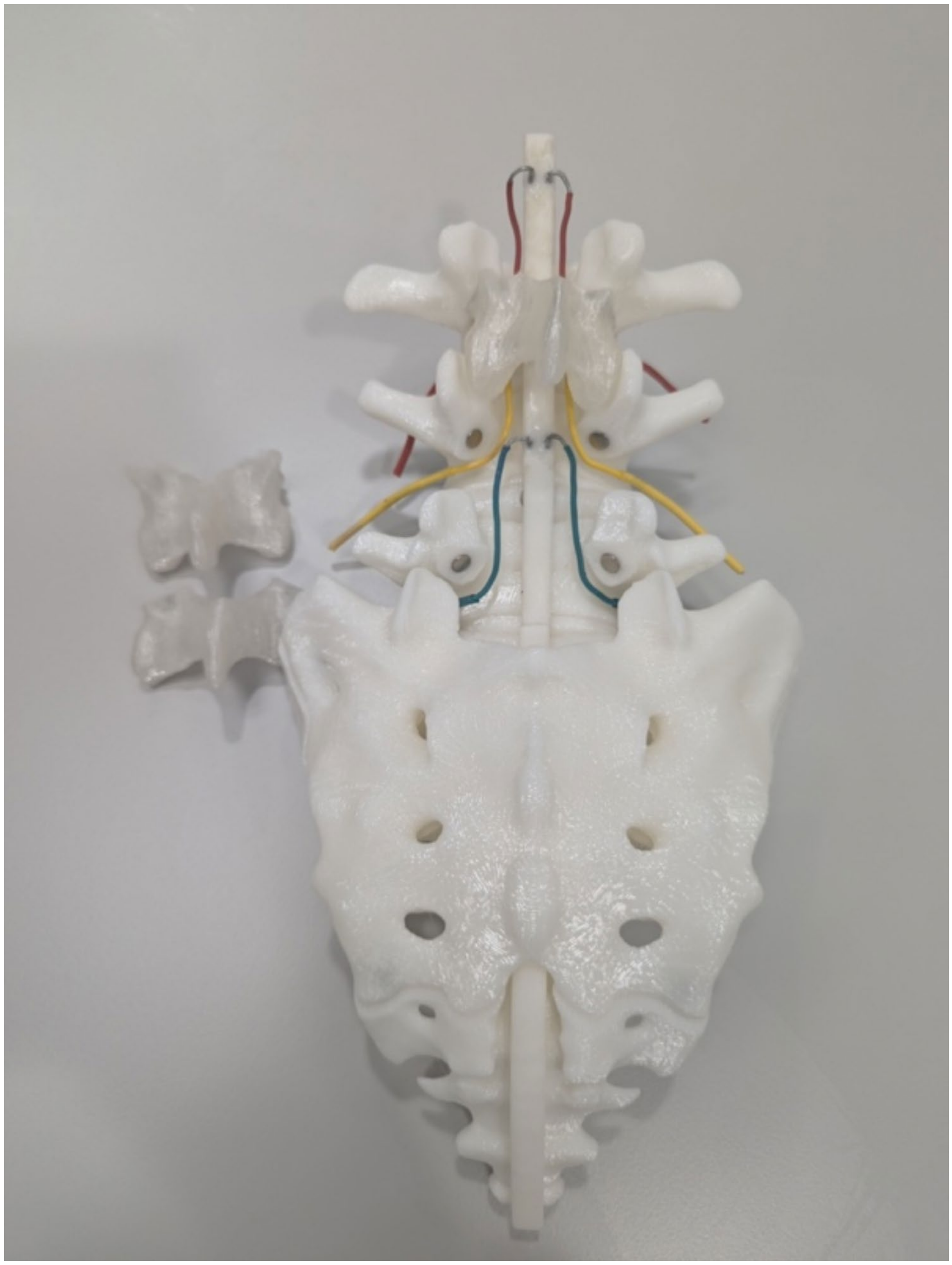

Fig. 2 The customised 3D-printed model with removable lamina

Activity worksheet

The students were presented with two clinical cases, one of which involved a patient with a prolapsed disc in the lumbar spine. This condition is frequently encountered in medical practice and can lead to spinal canal compression in the neural foramen and the lateral recess. Based on their knowledge of dermatome distribution and pain side, the team must provide an accurate anatomic pathology outline.

The first part of the activity required students to identify the location of disc prolapse (herniated disc) within the lumbar spine (4 points). They were instructed to place a 1 cm x 0.5 cm malleable blue tack on the 3DP and a similarly sized digital signature on the screen capture of DR to indicate the site of pathology. The second part of the activity (1 point) was to correlate the anatomical findings with the specific patient complaints, while the third part (1 point) was to explain how herniation can lead to neural compression and discomfort.

Appendix 1 is a sample of the worksheet and the outcomes for each task. Task A's outcome was identifying the location of disc herniation within the lumbar spine (LO1). For Task B, the teams had to correlate the anatomical findings with specific patient complaints (LO2),

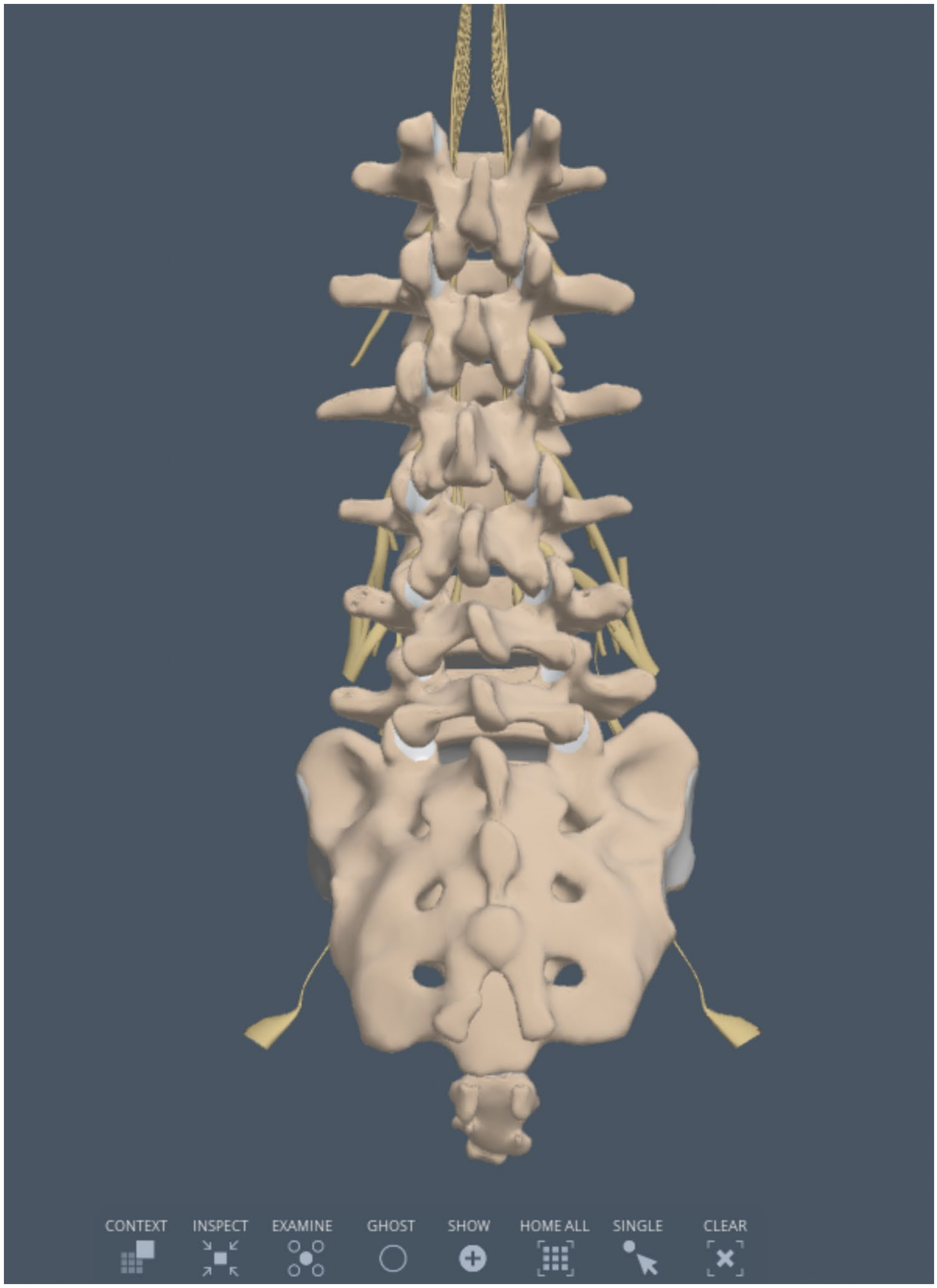

Fig. 3 Digital learning resource (Primal Pictures)

while Task C was to explain how disc herniation can lead to neural compression and resultant pain or discomfort (LO3).

The instructor graded the worksheets, and the results are presented in Table 1.

Statistical analysis

Statistical analysis was performed using IBM SPSS for Mac [36] version 29. An initial examination of data normality was performed using the Shapiro-Wilk test, indicating that the data was not normally distributed. Therefore, non-parametric statistical methods were chosen for further analysis [37]. A paired comparison was conducted within each intervention group to assess the changes in the team's performance using the Wilcoxon Signed-Rank test. To compare the differences in the interventions, the Mann-Whitney U test was utilised to measure the differences in scores between the 3DP and DR groups.

Table 1 Teams' clinical problem-solving performance and changes by scenario

Intervention	Team	Clinical Scenario 1			Clinical Scenario 2			Change		
		Task A	Task B	Task C	Task A	Task B	Task C	Task A	Task B	Task C
3DP-DR	1	4	1	1	2	0	0	-2	-1	-1
	2	4	1	1	2	1	1	-2	0	0
	3	4	0	0	2	1	1	-2	1	1
	5	4	1	1	1	1	1	-3	0	0
	6	3	1	0	4	0	0	1	-1	0
DR-3DP	7	2	1	1	4	1	1	2	0	0
	8	1	0	0	3	1	1	2	1	1
	10	1	1	1	4	1	0	3	0	0
	11	4	1	1	2	0	1	-2	-1	-1
	12	1	1	1	2	0	0	1	-1	-1

This study received an exemption from full IRB review and approval to conduct research by the National University of Singapore's Learning and Analytics Committee on Ethics (L2023-07-03). Participants provided informed consent to be recorded when they signed up for the optional tutorial session.

Results

Participant demographics

The optional Spine Anatomy session was conducted in October 2023 after a tutorial session, and 10 out of 12 teams attended, consisting of forty-six students (13 males and 33 females). Not all team members members within the group stayed back for the tutorial session. The age distribution was as follows: 35 students aged 20–25, 8 students aged 26–30, and 3 students aged 31–35.

Clinical problem-solving

Students solved the clinical scenario as a team, using either the 3DP model first, followed by the DR (Teams 1–6) or the DR, followed by the 3DP model (Teams 7–12). Each intervention team had 15 min to discuss and submit their answers before moving on to the next question. The instructor graded the submitted answers, and each team could score 6 points for each question. Table 1 summarises the performance of each team in solving the clinical scenarios.

A paired comparison of team performance across tasks and intervention was conducted using the Wilcoxon Signed-Rank test. The 3DP-DR group was found to have a noticeable decline in performance for Task A, with mean scores dropping from 3.8 ± 0.45 in Scenario 1 to 2.2 ± 1.1 in Scenario 2. The Z-value of -1.79 and a p-value of 0.07 indicate weak statistical significance. For Task B and Task C, the 3D-DR team's performance remained relatively stable, with mean scores of 0.8 ± 0.45 and 0.6 ± 0.55 across both scenarios, accompanied by non-significant Z-values of -0.58 and 0.00, respectively. In the DR-3DP group, performance on Task A increased from a mean of 1.8 ± 1.3 in Scenario 1 to 3.0 ± 1.00 in Scenario 2, although this change was not statistically significant (Z=-1.24, $p = 0.22$). Task B and Task C also displayed minor changes, with a slight decrease in mean scores that were not statistically significant (Z=-0.58, $p = 0.56$). Table 2 is a paired comparison of the team's performance across the different tasks and scenarios.

Table 2 Paired comparison of performance by task and intervention type

Intervention	Task	Scenario 1	Scenario 2	Z	*p*-value
		Mean (SD)	Mean (SD)		
3DP-DR	A	3.8 (0.45)	2.2 (1.1)	-1.79	0.07
	B	0.8 (0.45)	0.6 (0.55)	-0.58	0.56
	C	0.6 (0.55)	0.6 (0.55)	0.00	1.00
DR-3DP	A	1.8 (1.3)	3.0 (1)	-1.24	0.22
	B	0.8 (0.45)	0.6 (0.55)	-0.58	0.56
	C	0.8 (0.45)	0.6 (0.55)	-0.58	0.56

A Mann-Whitney U test was conducted to compare the team performances of the 3DP-DR and DR-3DP groups across different tasks in two clinical scenarios. In Scenario 1, Task A, there was a statistically significant difference between the groups, with a Mann-Whitney U value of 3.00 and a p-value of 0.03, indicating statistical significance in performance. However, no statistically significant differences were observed for Scenario 1, Task B and Task C, with p-values of 1.00 and 0.52, respectively. Similarly, in Scenario 2, no statistically significant differences were identified for Task A, Task B, or Task C, with p-values of 0.21, 1.00, and 1.00, respectively. Only statistically significant differences between the intervention groups were observed in Task A of Scenario 1.

Discussion

This study aims to understand how students use two different resources for anatomy education. Two clinical scenarios were designed with three tasks and three outcomes. The outcome of Task A was to identify the location of the herniation, while the outcomes of Task B and Task C were to explain the neural structures affected by the disc herniation and how the herniation can lead to resultant pain, respectively.

We found a difference in completing Task A (See Table 3) for the two intervention groups, but no difference between Task B and Task C for 3DP and DR. These results indicate that there may be a value in using 3DP in the context of visualisation and developing spatial relationships [38, 39], which was the outcome of Task A. Although the results of the activity did not show the difference in performance for Task B and Task C, the video recording of the learning activity showed that the learning tools has an impact on the learning process despite the results of the learning task showing no statistical significance.

The next section will use CHAT as a framework to analyse how the two learning tools were used in team discussions. Case 1 (Team 6) used the 3DP model first to answer Scenario 1, followed by DR to answer Scenario 2. For Case 2 (Team 10), DR was first used to answer Scenario 1, and 3DP to answer Scenario 2. The cases reveal intriguing controversies: Case 1 exhibited unexpected, small performance gain when using the DR tool on Task A, whereas Case 2 demonstrated anticipated improvements with 3DP on the same task. Despite this seeming paradox, the ensuing discussion will highlight the learning processes facilitated by the tools, making use of the CHAT framework to understand this learning process.

Case 1: using the 3DP

Team 6 consisted of 6 members who answered the clinical scenario using the 3DP model first, followed by the DR. Key observations include:

- **Initial interaction**: Upon receiving the model, G6-5 (Team 6, member 5) was the first to inspect and hold on to the model (tool), with G6-2 and G6-6 also looking at the model, pointing to different parts and engaging in light discussion (division of labour).
- **Focused discussion**: As the discussion became more contextualised to the clinical scenario, G6-1 and G6-5 used the model to refer to specific anatomical regions (object) to solve the clinical scenario (outcome). For example, G6-5 asked, "Does the nerve exit here?" while G6-1 took the model, dislodged a part, and explained the nerve's origin and exit.
- **Collaborative hypothesis building**: The 3DP model encouraged collaboration. G6-5 used the model to ask, "If you put it (the herniation) here, then this wouldn't be affected," to which G6-2 and G6-4 responded by pointing to inner structures. After deliberation, they agreed on the herniation's likely position and placed blu-tack on the model to indicate their final answer.
- **Continued engagement**: Even after submitting their answers, the team continued to discuss. G6-1 clarified with G6-3 by asking about the nerve causing pain, leading to further deliberation. The team even used alternative objects like a water bottle to model the spinal column, demonstrating that the 3DP model helped focus their discussion. However, in the end, the team went with their initial decision.

Table 3 Team performance across different intervention groups (3DP-DR vs. DR-3DP)

Clinical Scenario	Task	Mean (SD)	U	*p*-value
1	A	2.8 (1.4)	3	0.03*
	B	0.8 (0.42)	12.5	1.00
	C	0.7 (0.49)	10	0.52
2	A	2.6 (1.1)	7	0.21
	B	0.6 (0.52)	12.5	1.00
	C	0.6 (0.52)	12.5	1.00

Case 1: using the digital resource (DR)

After being briefed by the faculty (rules), the students in Team 6 launched the DR on their personal devices (tool), and the team broke up into three pairs (community). Key observations include:

- **Initial interaction**: After understanding the scenario, two pairs – G6-2 and G6-5, and G6-3 and G6-4 faced each other to discuss, with G6-1 occasionally joining in the discussion (division of labour). The two pairs mainly referred to G6-4's screen to discuss the task on a shared screen.
- **Challenges with software**: One pair had trouble navigating the DR. As G6-5 toggles the platform, the utterance "Oh no! No… okay, okay, try again" is heard, to which G6-2 points to G6-5's screen and suggests that G6-5 move the cursor. Upon further failed attempts to navigate the DR, G6-5 sounds out, "Why won't they let me move this thing down?!" G6-2 tries to help again, demonstrating students' initial struggle using the DR.
- **Fragmented collaboration**: Because the DR can be loaded on individual devices, students were observed using the software individually or in pairs at the start of the session, where they researched their own devices. It was only towards the end of the session that they started to discuss their hypothesis, but some were observed to be working individually on their own devices compared to when using the 3DP. Only 4 out of the 6 team members were observed to be collaborating. At the same time, the other two students appeared to be working on their own devices to solve the clinical scenario, occasionally joining the other team members.

From an activity theory standpoint, we can analyse the team's use of the DR compared to their use of the 3DP model. We found substantially less liveliness in the interactions between the subjects, the tool, and the community when using DR. In addition, there was less engagement with the activity rules (to answer the clinical question) and less need for a division of labour since each individual had the DR on their personal device. Table 4 is a summary of Team 6 interaction using the CHAT framework.

Case 2: using the digital resource (DR)

Team 10 consisted of 5 students and answered the clinical scenario using the DR followed by the 3DP model. Key observations include:

- **Initial interaction**: Upon receiving instructions, students adopted a semicircle position to start the discussion. Each student was observed to refer to their laptops, and their discussion centred around using the DR rather than the task itself.
- **Collaborative navigation**: For instance, G10-2 obtained the appropriate view of the region of interest and shared the settings with his team members.
- **Hands-on interaction**: G10-3 and G10-5 started discussing the anatomy of the region of interest, using their hands to model the direction of nerves in that spinal region, while G10-4 observed and listened in.
- **Challenges with software**: G10-5 has an uncertain tone, asking, "It connects like this, right…? And then it should touch…?" while modelling the nerves with her hands. In response, G10-3 stops modelling with her hands and says, "Ok, we got [the DR] to see how the nerves are running", – thus telling G10-5 not to speculate but to consult [the DR] instead. G-10-4 then replies, "Ya, it's just that I cannot [unintelligible] the thing," while figuring out the controls on her laptop, indicating her inability to configure the tool. G10-5 frustratedly remarks that she cannot "get it" (get the correct anatomical structures to appear).
- **Frustration**: G10-5's frustration was evident as she remarked that she could not "get it" (get the correct anatomical structures to appear). This exchange highlighted the challenges of using the DR despite having had access to it since the beginning of the semester.

Overall, the subjects referred to their laptops, and their discussion centred around using the DR (the tool), rather than accomplishing the task's learning outcomes. Thus, the DR did not facilitate a discussion contextualised to the rules within the activity system. The discussion was less grounded in the task's demands than the discussion using the 3DP model (see next section).

Case 2: using the 3DP

Upon receiving the 3DP model, the subjects in Team 10 moved away from the desk and formed a semi-circle discussion-style seating arrangement. Key observations include:

- **Initial interaction**: The subjects shared the tool (the model) and took turns familiarising themselves with it and manipulating its different parts first. For example, G10-1 received and manipulated the model by removing the pedicle and other modular structures and handing the parts to G10-2 and G10-3. The sentiments initially toward the 3DP model were that of intrigue.
- **Sub-team exploration**: At one point, the team of 5 splits into a pair and a trio, and each sub-team likewise explores their 3DP model fragment. At this stage, each student held on to a different part, and

Table 4 Team 6 discussion analysis using CHAT

CHAT Interaction	3D-Printed Model	Digital Resource
Between subject and tool	G6-5 is the primary handler of the tool. She inspects it and holds on to it. The other groupmates also look and point to the model initially. As the discussion progresses, more groupmates get their chance to hold onto and manipulate the model.	Each student launched the DR on their personal devices. There did not appear to be much collaboration at the start
Between subject, tool and community	The students shared the model, passing the model around and exploring the parts together. G6-5 offered the team alternative hypothetical clinical scenarios while referencing the model, extending its use past the clinical scenario and bringing in own clinical knowledge.	G6-5 runs into issues with the DR and G6-2 assisted.
Between subject, community, tool, division of labour, object and rules	Some students (subject) read the prompt out loud (rules) to their teammates (community) while other students manipulate the tool with reference to the prompt (object). The different roles undertaken by the various subjects demonstrates division of labour.	Groupmates who had trouble configuring the tool consulted other groupmates (division of labour). We did not observe evidence that the team (community) engaged in explicit discussion of the task prompt (object and rules).

the team explored the 3DP model with the shared motivation of using it to answer the question.

- **Collaborative discussion**: Eventually, the 3DP was held by one person who manipulated it demonstratively in front of the rest of the team. This enabled the team to collaborate when answering the clinical scenario. For example, G10-1 held the model and asked the team, "How many lumbar [vertebrae are there]?" G10-3 reached out her hand to count the vertebrae on the model.
- **Focused discussion**: The discussion continued to be more contextualised, where students were observed to work together and referred to the model by rotating it to confirm the nerve location. G10-1 held the model and asked, "[The pain is on the] right thigh? [The nerve] doesn't cross, right? It just goes straight, right? So this is the back, this is the right… so the herniation is here" to confirm the position of the nerve and location of the patient's pain.

Using the 3DP model allowed students to build their team's hypothesis in answering the clinical question. G10-5 used her hands to model the different ways the hernia could be causing the nerve compression, thus engaging with the model to achieve the desired clinical outcome. G10-3 listened to G10-5 and took the model to question, "But, the hernia can be pushed out from here, right?". After some back and forth, referencing the model and other teammates' ideas, the team comes to a consensus, evident in their repeated utterances of "Ohh, [that's] correct". G10-5 then checks, "Everybody now understands?" before placing the blu-tack in place and finalising their answer. Table 5 is a summary of Team 10 interaction using the CHAT framework.

This section discussed how CHAT was used as a framework for understanding the student learning process using two tools. We reflected on how these tools (3DP and DR) had a direct observed effect on the individual student learners (subject), team (community), clinical scenario (object), and their final answer to the clinical scenario (outcome). The tools indirectly affected learning, mediating the learning of the individual learners and how they interacted with the team (community) through collaboration (division of labour) in the clinical scenario. We did not observe the effect of the system's object on the community or the rules. Figure 4 is a summary of observed interactions using the CHAT framework.

The observations from both Case 1 and Case 2 highlight the contrasting impact of the tools (3DP and DR) on students, team dynamics and learning outcomes when observed through the CHAT framework. The analysis reveals that while the 3DP promotes collaboration and team discussion by effectively integrating the subject, tools and community, the DR may hinder these elements by isolating individual efforts in completing the task. These findings underscore the importance of selecting the appropriate education tool to facilitate meaningful learning.

Conclusion

Although the team's ability to complete the learning task using 3DP or DR had no statistical significance, this study showed that there were rich learning insights using the CHAT framework. A key observation from both teams was that the 3DP facilitated higher student engagement and collaboration. This is because tangible physical models can promote active learning [4, 9] and provide better spatial understanding. In contrast, the DR often led to fragmented interaction, with students struggling with the software navigation and working more individually.

Based on the observation from the two cases, more of the students in each team were engaged in discussion when using the 3DP than the DR. We found that students were engaged in more authentic discussion [40] in

Table 5 Team 10 discussion analysis using CHAT

CHAT Interaction	3D-Printed Model	Digital Resource
Between subject and tool	The students took turns to familiarise themselves with the model and manipulate its different parts first.	Individual students worked on their own laptop to configure the DR.
Between subject, tool and community	The students asked each other questions about clinical knowledge (e.g., G10-1 explaining what a herniation means). The students shared the model, passing the different parts around and exploring the parts together (e.g., G10-1 manipulating the model by removing the pedicle and other modular structures, handing the parts to G10-2 and G10-3).	The students consulted each other for help on how to operate the software.
Between subject, community, tool, division of labour, object and rules	Some students (subject) read the prompt out loud (rules) to their teammates (community) while other students manipulate the tool with reference to the prompt (object). The different roles undertaken by the various subjects within the community demonstrates division of labour.	Only G10-2 (subject) managed to use the DR in its intended way and in-context – to solve the clinical question (object and rules). His answer was eventually the submitted answer as he was the only one who was able to use the tool efficiently (division of labour). Groupmates who had trouble configuring the tool consulted other groupmates (division of labour).

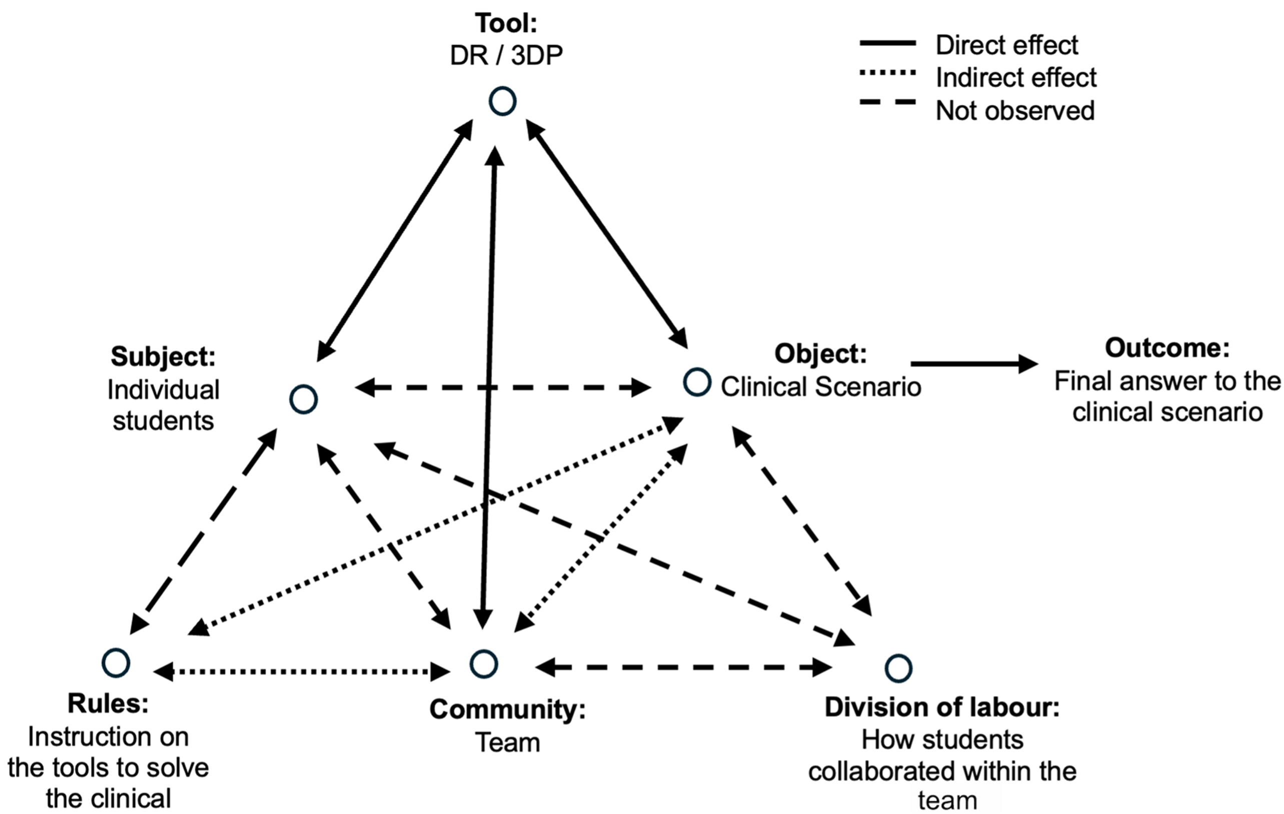

Fig. 4 Observed interactions using the CHAT framework

the form of classroom talk that is purposive and engaging. Students engaged in authentic discussion are driven by inquiry rather than simply a monologue, which was observed from the two case studies presented. One possible reason could be that the 3DP was more intuitive and easier to use than the DR, which has many features and functions. We observed that students took some time to re-familiarize themselves with the DR and, therefore, overall, significant time to answer the clinical scenario.

From a collaborative standpoint, students were engaged in more collaborative discussions when using 3DP than DR. The 3DP can be taken apart and shared among the students, allowing for the physical manipulation of the model with other team members engaged in the discussion. In contrast, the DR is limited to the laptop screen, making it logistically challenging for more than four students to view one screen. One way around this could be to have a larger interactive touch screen where students can project their work to make their learning visible [41], which may encourage students to be engaged in collaborative learning.

The chosen DR (Primal Pictures) is a full-featured anatomy software that our clinical faculty highly recommended [5]. Despite giving students access to the system early in the semester, faculty members did not actively require students to access the system. This translated to students' unfamiliarity with the system, which was observed in the video recordings, where many students struggled with accessing the system at the start. Therefore, it is essential to ensure students are familiar with the system to fully benefit from its affordances and engage in authentic learning.

Educators must consider the content of educational tools and their interactive potential. While DR offers extensive anatomy information, it may inadvertently create barriers to collaborative learning. The 3DP model, by contrast, seemed to encourage physical interaction naturally, shared exploration, and collective hypothesis-building. However, the 3DP is limited by the model design and has a limited use case. Therefore, it is important to strike a balance to ensure that the tools used help students achieve the learning outcomes.

This study used cultural-historical activity theory to provide insights into students' interaction and shed light on the underlying processes influencing their engagement in the learning activity. Using this framework, we identified two case studies that found learning was more meaningful when students could fully engage in the discussion and when the learning tool was specific and targeted their needs and context. The right tools can promote student agency [42] and ownership of the learning process. In turn, students will contribute more to the discussion and take ownership of their learning experience.

Limitation

The conclusion of this study can only be generalised to our medical school, which uses a team-based learning approach. This means that students were familiar with working together as a team and, therefore, may not face issues of team dynamics that newly formed teams may face. In addition, we could have better-prepared students to refresh themselves on using the DR before the session so that they could spend less time figuring out the software. We should also have provided a preset view of the lower spine so that students do not need to navigate around to obtain the appropriate view.

For future iterations of the study, we will consider using multiple cameras to capture students' interactions to help better understand what was happening when students were working individually on their computers. This study also did not consider other factors that may affect student learning, such as motivation, prior knowledge, and metacognitive processes, which may impact students' engagement during this learning activity.

Supplementary Information

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Supplementary Material 1

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Author contributions
JWYL, DWHO, FB, and RCCS were involved in the conceptualisation, data collection and design of the study. JWYL, LXTL, FB and RCCS were involved in the analysis and interpretation of the data. JWYL and LXTL drafted the manuscript with critical input from FB and RCCS for important intellectual content. All authors reviewed and provided final approval for the final work, ensuring that any concerns regarding accuracy or integrity were appropriately investigated and resolved.

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Data availability
Data may be provided by the authors upon request.

Declarations

Ethics approval and consent to participate
This study adhered to the principles of the Declaration of Helsinki and received Exempt Approval from the Learning and Analytics Committee on Ethics, National University of Singapore (Approval Ref: L2020-12-01). All study participants provided written informed consent prior to taking part in this study.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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