(Board 57/Work in Progress) Immersive Learning: Maximizing Computer Networks Education Based on 3D Interactive Animations

Yixin Zhang, University of Toronto

Yixin Zhang is an undergraduate student in computer engineering at the University of Toronto (graduating in May 2024). Her research interests include computer networks and digital communications.

Hanzhang Xing
Yaqi Zhang, University of Toronto

An ECE student from university of Toronto.

Xinyan Du, University of Toronto

Xinyan Du is a fourth-year Computer Engineering student at the University of Toronto. She is proficient with C, C++, Python, SQL, and JavaScript.

Dr. Hamid S Timorabadi P.Eng., University of Toronto

Hamid Timorabadi received his B.Sc, M.A.Sc, and Ph.D. degrees in Electrical Engineering from the University of Toronto. He has worked as a project, design, and test engineer as well as a consultant to industry. His research interests include the applicati

WIP: Immersive Learning: Maximizing Computer Networks Education Based on 3D Interactive Animations

Abstract

The potential of 3D animation models can enhance the learning process, making it more vivid and clear by capturing students' attentions. As concepts related to computer networks are often abstract and intricate, educators commonly resort to using text and static images, which may potentially limit students' understandings of these complex topics.

The primary goal is to fill the void in networking education by introducing an interactive 3D model. This innovative approach is designed to empower educators with effective tools for conveying intricate concepts, enriching the learning experience through dynamic and captivating visualizations. Accessible via a user-friendly website, our 3D model makes the learning process of computer networks knowledge immersive, smooth, and intuitive.

To assess the effectiveness of our design in terms of users' overall experience while interacting with the animations and their improvements on knowledge requirements, a trial survey was conducted among users, in two groups of students—with and without prior knowledge of computer networks. The feedback received from both groups verify the effectiveness of our design that 87.5% of inexperienced learners found intuitive and simple to use; and 70% of experienced users noted that this design helped them review and deepen their understanding.

1 Literature Review

Multimedia resources are widely used in modern education and provide innovative and effective learning experiences. Studies on the cognitive advantages of multimedia in education, such as Mayer's cognitive theory of multimedia learning, emphasize its potential to enhance learning through dual coding and multisensory engagement [1]. Among various multimedia methods, 3D interactive animation is renowned for its vividness and ability to visualize objects in a dynamic and intuitive way [2]. Many studies have reported positive results and proved the effectiveness of 3D animation in education. The study by Zakir et al (2021) designed a 3D animation program, for learning hydrocarbon compounds, demonstrated high usefulness with 94% effectiveness rating [3]; another design for anatomy education carried out by Jinga et al (2023) also concluded that 3D interactive animation medical education by enhancing learner’s understanding and interpretation ability [4]. More similar works revealed that 3D interactive animation can simulate abstract concepts, attract learners through interaction, and visually enhance learner’s understanding.

Although the effectiveness of 3D animation has been proven in various educational fields, its usage for computer network learning is still sparse. Existing resources, which encompass 2D illustrations or tutorial-style videos (Appendix A), are mostly exam-oriented and do not cover the deep concepts and abstract details of computer networks. However, such intangible concepts in computer networks, especially the complicated interactions within network systems, impose learning challenges to students' understanding and participation. Therefore, there exists the need for implementation of 3D interactive animations to effectively demonstrate the concepts of computer networks.

To bridge this educational gap, we are proposing a 3D interactive animation module for computer networking learning. The design is an educational tool by incorporating aesthetic visual elements. Each core concept is encapsulated in sophisticated 3D animations that enable learners to acquire computer networking concepts systematically and deeply through an immersive and interactive learning experience. Our 3D models are accessible through a user-friendly website, making computer networking knowledge easily accessible to a wider audience, beyond the limitations of traditional classroom settings. This design takes the pedagogical framework and principles of interactive learning into account and collaborates with educational experts to improve practicality.

The detail of technical design is outlined in Section 2, and Section 3 presents the results of our tests and evaluations. Section 4 dedicated to discussing potential paths for future work.

2 Design Backgrounds and Modules

System level overview

We implemented a website with organized content, featuring an animation module with an interactive 3D model created in an animation software, Blender [5]. The design follows an industry de facto TCP/IP suite protocols [6]. The website includes an overview page with five modules, covering animation module, application, TCP transport, and data link layers, along with common elements like a logo and navigation bar. The animation module showcases the packet transferring through routers and switches after initiating a web-browsing request from client to client using a 3D model. To enhance interactivity, we connect HTML elements, including interactive buttons and annotations, to the Blender model using Verge3D [7] that allows connection between HTML and Blender. This integration enables users to manipulate animations and explore detailed information about the packet transfer process, leading to a more engaging and immersive experience. The system level block diagram is shown in Figure 1.

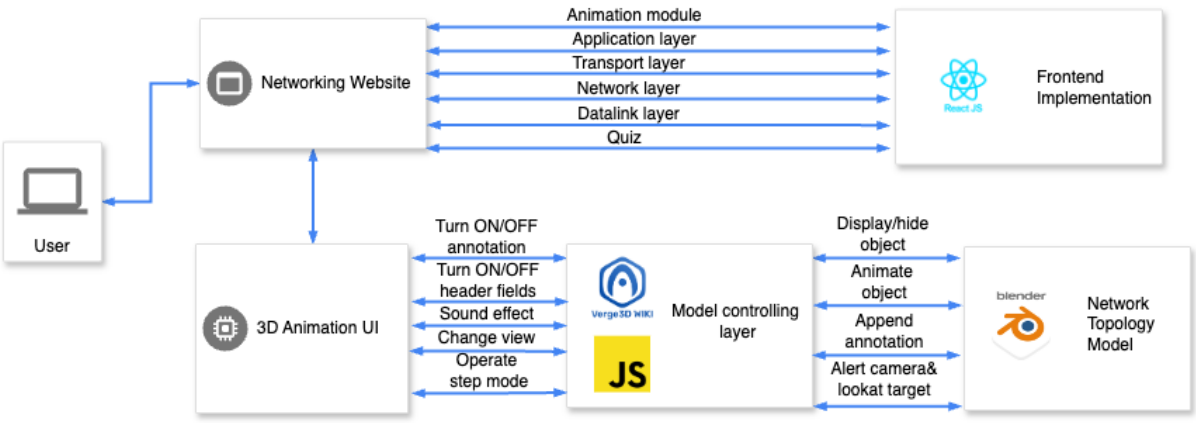

Figure 1: System overview diagram (Expanded version in Appendix B)

Module development

- Blender (Animation)

We created a 3D model that includes an animation depicting the transfer of packets from one PC to another, passing through various routers and switches, using Blender [5]. In addition to illustrating the fundamental topology of packet transportation, we incorporated different

camera views in Blender. This feature enables users to view from multiple angles for a detailed examination of each process. The blender model includes labels indicating the position of the packet header and annotation buttons, as well as information related to different layers and router routing tables.

- HTML (interactive button and annotation)

To streamline the Blender model, we introduced interactive elements using HTML. We designed buttons that can reveal the header information integrated into the Blender model. Additionally, we implemented a popup window that provides a clearer display of the header information at the top of the window. The annotation window, featuring an actual device image, is also constructed using HTML.

- Verge3D (Animation)

We employed Verge3D puzzles to establish a connection between the Blender model and HTML elements, enabling interactivity on the website. Through this integration, we incorporated device annotations and camera icons, facilitating functions such as switching camera views, expanding and hiding device details and routing tables, and zooming to observe different blocks by clicking various buttons. This module transforms the animated model into an interactive experience, empowering users to manipulate the animations.

- React.js

We implemented the website according to the designed UI using the React.js framework. Within this module, we organized the animation model and computer networking content, making them accessible through the website. The website comprises the landing page, layer overview page, and common elements like logo and navigation bar. The layer overview page presents four modules - the animation module, TCP layer, transport layer, and data link layer. The animation module features an interactive 3D model and an animation explanation subpage. The other three modules contain the knowledge of each layer on the corresponding subpages.

3 Methods

Survey Plan and Evaluation

The testing verifies the effectiveness of our design. The test plan includes internal testing and external testing. The internal testing focuses on the functionality of 3D animation and incorporates the 3D animation with the webpage. The external testing focuses on the user experience of the website. Appendix C summarizes the specific measure of the testing plan.

The internal testing was done by the design team, in which we passed all the technical and functional metrics. The external testing was associated with gathering feedback from student volunteers with an online survey. The survey was performed with a group of 29 students. The main goal of the survey is to investigate and test the usability of the design. To ensure a fair assessment of our design's effectiveness, the participants were exclusively exposed to our design. Usability testing measures the user experience from the scale of Strongly Disagree (1) to Strongly Agree (5) in three aspects: helpfulness for learning, performance of the platform (website and 3D animation), and aesthetics of the design, with short answer feedback that the user wants to leave with us.' The complete survey questions and result statistics are detailed in Appendix D.

External Testing Result

The participants in the testing had diverse familiarity with computer networks, including:

- 16 students with little prior experience in learning computer networks (scale of 1-2)
- 13 students with prior experience in learning computer networks (scale of 3-5)

Helpfulness for learning:

Among 29 survey participants, 22 people indicated they improved their understanding of computer networks (scale of 4-5) with 3D animation. Within the 22 people, seven of them indicated they improved significantly. We also quantify users' ability to acquire knowledge from the design by comparing the quiz (Appendix E) results before and after the test process. Table 1 shows the degree of correctness based on their prior experience to the subject.

Understanding of computer networks (Scale: 1-not familiar to 5-Very familiar)	Rate of correctness before viewing website	Rate of correctness after viewing website	Improvement rate
1-2 (16 inexperienced)	35.1%	78.9%	43.8%
3-5 (13 experienced)	67.3%	88.5%	21.2%

Table 1: the rate of correctness of two groups of testers

The quiz correctness of both inexperienced learners and experienced learners has been improved. For the inexperienced learner, the improvement rate is 43.8% and experienced learner is 21.2%. This outcome supports the website's effectiveness for experienced learners in reviewing existing knowledge and its user-friendly nature for entry-level learners to acquire new knowledge.

Performance:

On average, 84.5% of the users found the performance of the 3D animation and website smooth. They were able to figure out the features implemented in the design without any guidance. There was no error encountered. 82.8% of people thought the loading time of the design is acceptable. Figure 2 shows the outcomes of performances for website and 3D animation model, respectively.

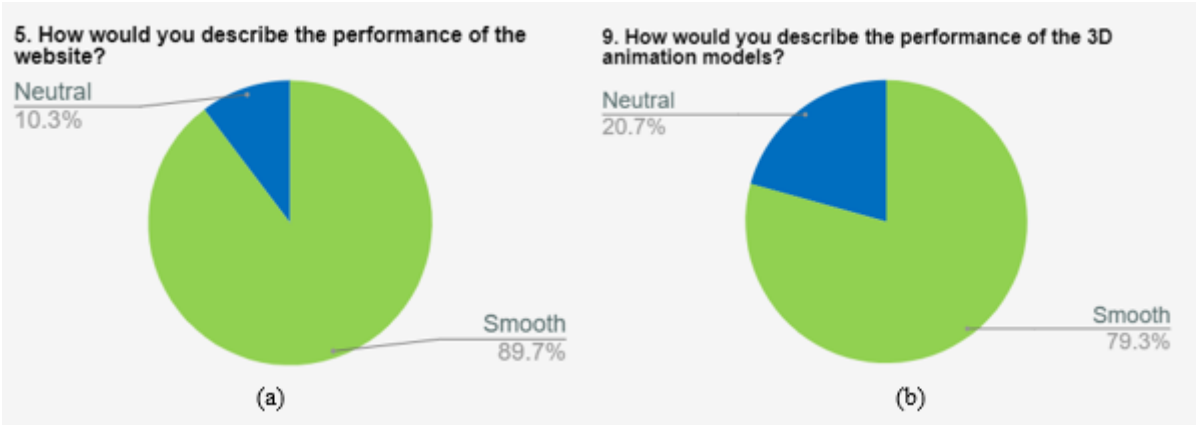

Figure 2: Survey result of question on "performance of website/3D animation model" (a) is for the website with 89.7% of users agreeing on smooth usage; and (b) is for 3D animation model that 79.3% of users thinks smooth.

Aesthetic:
All of the users rated the design, color, and layout of our 3D animation models with a high score, meaning the user interface of the design is appealing, interactive, and interesting to users. Figure 3 plots the outcomes for the website and 3D animation model, respectively.

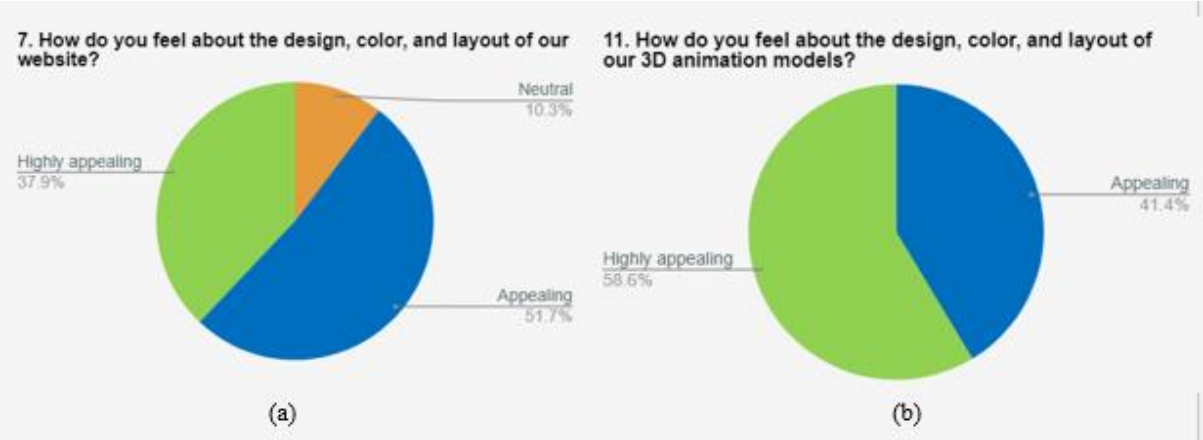

Figure 3: Survey result of question on "aesthetic design of website/3D animation model" (a) is for the website and (b) is for 3D animation model. There was no user rated "unappealing" or "very unappalling" so these two scales are not displayed on the charts.

Conclusion and Discussion
It can be concluded that all of the users both experienced and inexperienced, rate the overall usefulness and aesthetic of the design with a high score. And they understand computer networks knowledge better indicated by the improvements of their quiz correctness. Participants are also willing to recommend this project to more people, indicating a tendency that 3D animation as a visualization tool exceeds the performance of 2d and plain text on helping people better understand the concept in networking.

4 Future Work

In the realm of future work, two crucial areas for refinement and development are technical improvements and scalability to other engineering courses. The survey collected areas that users suggest to have, such as voice channel, hint navigation, and real-world networks cases. We aspire to enhance the user experience based on such inputs. Additionally, efforts will be directed towards technical optimizations, such as refining loading times and overall system performance. By leveraging advancements in various attractive multimedia formats and web optimization routines, we aim to create an efficient and user-friendly platform that aligns with the evolving landscape of multimedia education.

In terms of content expansion, our endeavor is to broaden the scope of the 3D interactive model to encompass a more comprehensive array of engineering topics. By collaborating with subject matter experts, we aim to integrate various engineering concepts into the model to facilitate learning experience for areas such as electromagnetism and photonics. This expansion not only ensures a more intuitive presentation of subject knowledge but also meets the diverse needs of learners with different levels of knowledge base, providing a richer educational experience.

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[11] Aaron, How the Internet Works in 5 Minutes. (Feb. 18, 2009). Accessed: Dec. 16, 2023). [Online video]. Available: https://www.youtube.com/watch?v=7_LPdttKXPc&ab_channel=Aaron.

Appendix

Appendix A - List of online resources about computer networks

A list of popular online resources that explain computer networks is shown in Table 2. They are lecture-based with nice animation design but very general contents.

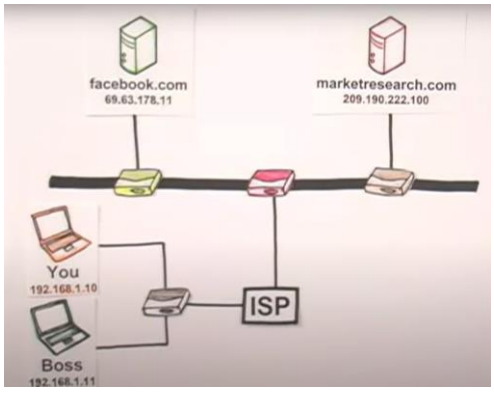
Name of the resource	Observation	Screenshot
Computer Networks: Crash Course Computer Science [8]	A speaker explains the concepts of computer networks in general, along with the history and fun facts. The video does not cover very technical or in-depth knowledge. Animation has colorful graphic design.	
PowerCert Animated Videos [9]	A series of videos about computer networking, with an emphasis on the hardware (wires and device structure). The animation consists of slides and gif components. Data, such as webpage and IP addresses, is fabricated.	
IT k Funde - Networking & Infra Concepts [10]	Tutorial videos teaching networks, that covers theoretical contents of computer networks without experimental data. A speaker talks while writing on a white board.	
How the Internet Works in 5 Minutes [11]	An overview video about how the internet works, especially which parties are involved in the packet transfer. The content is general, without protocol or layers of information. The animation is not computer-based rather recording the physical paper and drawings.	

Table 2: Existing online resources of computer networks animations

Appendix B –Expanded system diagram

Expanded version of the system diagram, including the animation module figures.

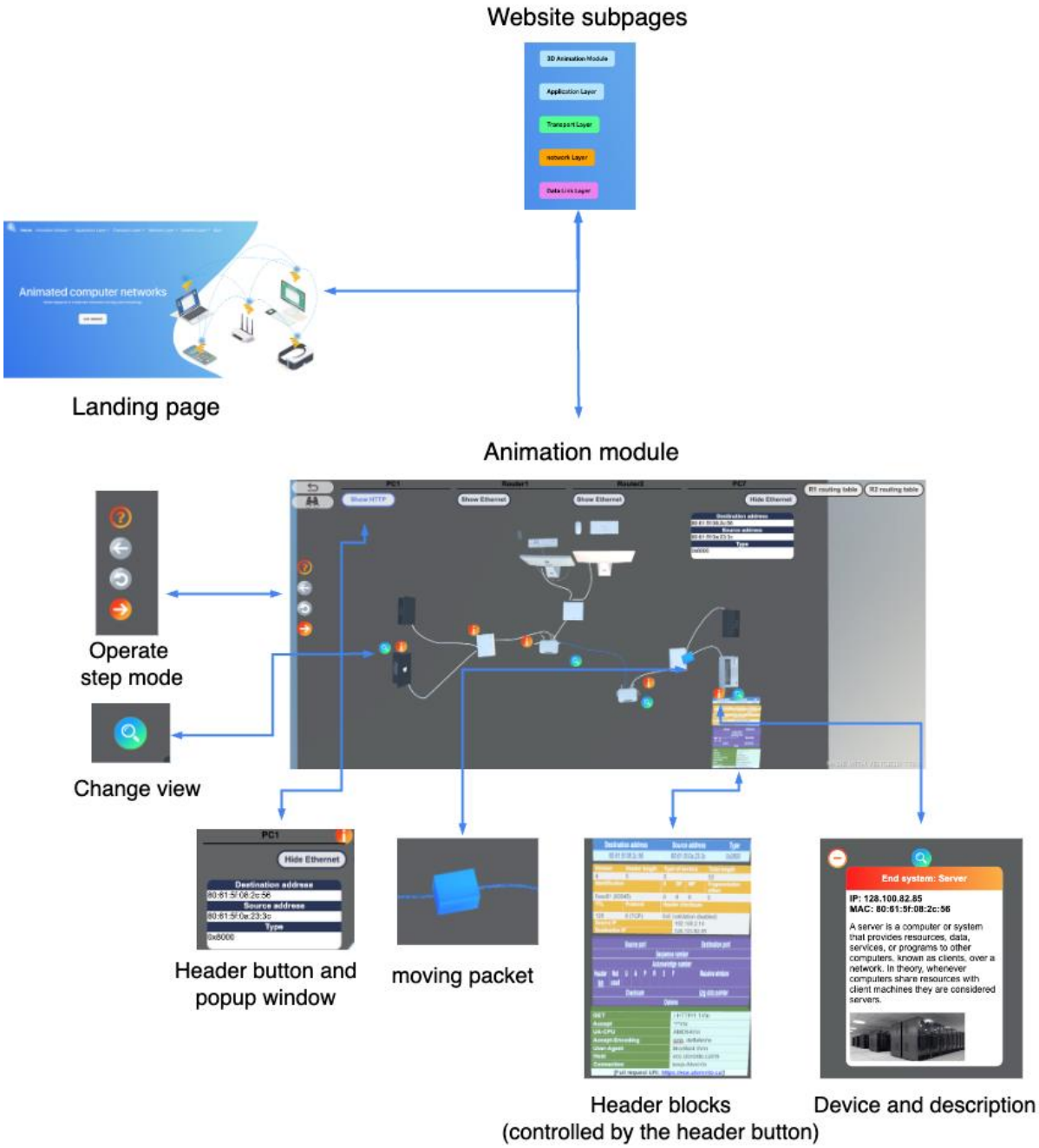


Figure 4: Expanded version of the system diagram

Appendix C - Specific measures for testing

Table 3 is the internal testing that was conducted to ensure functionality prior to students' tests.

Design Specification	Objective Measure	Evaluation Criteria
Functional requirements		
The 3D animation module has display text or pause features.	Presence of pause or display text features within the animation model	Pass: Interactive features are implemented. Fail: No feature is implemented.
The website supports in all commonly used browsers (Chrome, Edge, Safari, Firefox) [6]	Behavior in browsers	Pass: No error and behave consistently in different browser Fail: Error occurs in specific browser
Aesthetic Considerations		
All the pages on the website have a consistent style.	Font size and style across different pages	Pass: Follow font size standard: 25px with title and 16px with paragraph Fail: Not following the standard

Table 3: specific measures for internal testing (development group)

Table 4 presents the external testing performed by students.

Design Specification	Objective Measure	Evaluation Criteria
Functional requirements		

Users acquire layer model knowledge in computer networks from our project.	Quiz results before and after using the 3D animation module and website	Pass: Experienced users to the subject: achieve 10% improvement. Inexperienced user: reach 50% correct rate.
The website supports in all commonly used browsers (Chrome, Edge, Safari, Firefox) [6]	Behavior in browsers	Pass: No error and behave consistently in different browser Fail: Error occurs in specific browser
Aesthetic Considerations		
All the pages on the website have a consistent style.	Survey result from users (target on design aesthetic)	Pass: Accepted by users. Fail: Receive complaints from user.
User experience		
Clear pathways on the website to access 3D animation	Presence of navigation element, Usability testing, survey	Pass: User navigate with ease Fail: User has difficulty locating 3D animation.
The loading time is acceptable.[7]	Survey result from users (target on page loading time)	Pass: Accepted by users. Fail: Receive complaints from user.

Table 4: specific measures for internal testing (development group)

Appendix D: Survey questions

The survey on our website is listed below, which we refer “Netlearning” as the name of our product.

1. Before using Netlearning, what was your level of familiarity with computer networks?
   1-not familiar to 5-Very familiar

2. After using our product, how much has your understanding of computer networks improved?
   1-No improvement at all to 5-Significant improvement

3. Is knowledge classified neatly?
   1-Not neat at all to 5-Very neat

4. Are contents easy to find when you want to review?
   1-Very hard to find to 5-Very easy to find

   Please recall your experience of interacting with our product (website and 3D animation)

5. How would you describe the performance of the website?
   Smooth
   Neutral
   Experienced errors (please describe the errors you encountered below in "Others")
   Other _____

6. How would you rate the loading time of our website?
   1-Very slow and annoying to wait to 5-Very fast

7. How do you feel about the design, color, and layout of our website?
   1-Very unappealing to 5-Highly appealing

8. How intuitive did you find our website to use?
   Very intuitive – easy to navigate and use
   Somewhat intuitive – use it with little difficulty
   Neutral – manageable but sometimes unclear
   Somewhat unintuitive – struggle to understand how to use it
   Not intuitive at all – challenging and confusing to use
   Other_____

9. How would you describe the performance of the 3D animation models?
   Smooth
   Neutral
   Experienced errors (please describe the errors you encountered below in "Others")
   Other_____

10. How would you rate the loading time of our 3D animation model?
    1-Very slow and annoying to wait to 5-Very fast

11. How do you feel about the design, color, and layout of our 3D animation models?
    1-Very unappealing to 5-Highly appealing

12. How intuitive and easy to follow did you find the 3D animation in Netlearning?
    Very intuitive – easy to interact and follow the model
    Somewhat intuitive – use it with little difficulty
    Neutral – manageable but sometimes unclear
    Somewhat unintuitive – struggle to understand how to use it
    Not intuitive at all – challenging and confusing to use

13. Please rate the overall usefulness of Netlearning:
    1-Very poor to 5-Excellent

14. Which features of Netlearning do you like the most?

15. What additional features or enhancements would you suggest for Netlearning?

16. Please share any additional comments or suggestions about your experience with Netlearning:

17. Will you recommend this product to others?
    1-Very unlikely to 5-Very likely

Appendix E: Quiz questions

A Quiz was conducted to measure the depth of learning by students.

1. Which of the following is the correct order of encapsulation?
    a. Network - Data link - Physical
    b. Application - Transport - Network - Data link
    c. Transport - Application - Network - Data link
    d. Physical - Data link - Network - Transport - Application

2. HTTP is deployed on which of the following layers?
    a. Application layer
    b. Network layer
    c. Transport layer
    d. Data link layer

3. Which of the following layer is not included in the TCP/IP model?
    a. Presentation layer
    b. Network layer
    c. Application layer
    d. Data link layer

4. Which of the following belongs to the transmission device?
    a. Switch
    b. Cookie
    c. Cable
    d. Public key

5. Which fields of IP header is IP address filled?
    a. Source IP
    b. TTL
    c. DF
    d. Header checksum

6. Which field is changed during the packet transmission?
    a. Network header - TTL
    b. Network header - version
    c. Ethernet header - Type
    d. Network header - DF

7. Which of the following is the user input URL?
    a. Ece.utoronto.ca
    b. 1 Yonge st.
    c. 147.322.51.1
    d. 80:61:5f:08:2c:56

8. Based on the longest prefix match and routing table provided below, the IP address 204.100.12.0 should be directed to which interface?

Destination	Subnet mask	Interface
192.168.0.0	255.255.0.0	Eth0
112.34.0.0	255.255.255.0	Eth1
159.96.0.0	255.255.0.0	Eth2
default		Eth1

    a. Eth0
    b. Eth1
    c. Eth2
    d. None of above