ANALYSIS OF 3D MODELING SOFTWARE USAGE PATTERNS FOR K-12 STUDENTS

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ABSTRACT

In response to the recent trend in maker movement, teachers are learning 3D techniques actively and bringing 3D printing into the classroom to enhance variety and creativity in designing lectures. This study investigates the usage pattern of a 3D modeling software, Qmodel Creator, which is targeted at K-12 students. User logs containing participants' operations were recorded and analyzed. We expect the results to be instrumental to the developers of Qmodel Creator regarding future enhancements of the software. Moreover, by observing operation behaviors of K-12 students, lesson plans for 3D printing can be tailored to fit the needs of users of different education levels.

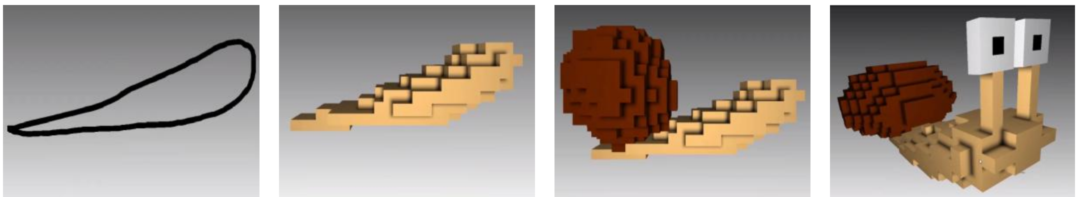
KEYWORDS

3D modeling software development; Qmodel Creator; K-12 education; STEM lesson plan; User behavior analysis

1. INTRODUCTION

3D Modeling software has become popular in recent years due to advances in 3D printing technology as well as affordability of 3D printers. According to a research report by Gartner, 2016 shipments of 3D printers will exceed 490,000 units. The report also stated that major clients for products below $2,500 are schools and universities that need to lower procurement costs (SC, 2015). Many training courses in several professional areas, such as medicine (Mahmoud & Bennett, 2015), architecture (Cesaretti *et al*, 2014), and machinery (Gonzalez-Gomez *et al*, 2012), often incorporate 3D printing in their lecture cases. An increasing number of teachers in elementary education also plan to learn 3D-related techniques and apply 3D printing directly in their courses (Irwin *et al*, 2014).

The overall process of 3D manufacturing includes the following stages: 1) modeling using software or scanning, 2) editing and refining and 3) printing using additive or subtractive manufacturing. There is no doubt that 3D printing is beneficial for K-12 education as it ignites children's imagination and creativity. It is also critical to include modeling concepts in STEM courses. However, current K-12 lecture cases focus too much on the printing phase of the process, possibly due to the complexity of 3D modeling and editing software. To ease the learning curve of modeling for K-12 students, we have developed Qmodel Creator, a cubic style modeling software with an intuitive user interface that quickly converts 2D drawings into 3D models. Figure 1 shows how the 3D model of a snail is generated using very simple sketches.



(a) (b) (c) (d)

Figure 1. Demonstration on how to create a snail using Qmodel Creator. (a) Sketch a contour, (b) System generates a rough model with thickness adjustment, (c) Sketch another part then combine all components into one, (d) Adding details to the model

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In order to understand the user behavior and provide feedback for updating the user interface and functions of the application, we recorded operation logs of participants who tried out Qmodel Creator in several workshops. The following questions were posed and answered based on the analytical results derived from the recorded information:

- For models created with Qmodel Creator, what is the degree of completion?
- Which function is used more frequently: intuitive modeling or traditional 3D editing (such as adding and deleting voxels)?
- When users create models, is the process smooth? Is trial and error needed?
- How long does the user take to finish a modeling task?

In this paper, firstly, we found that there is detectable distinction in the detail of the finished models for users from different skill level groups. Furthermore, our analysis indicated that students with different backgrounds have respective preferences on particular functions of Qmodel Creator. At last, we examined the operation logs and concluded that Qmodel Creator is a suitable 3D modeling software for all ages of K-12 students.

The remainder of this paper is organized as follows. In Section 2 we outline related works on lesson plans, user interface design, and user behavior analysis research. Section 3 elucidates our experiment process and methodology, as well as the indicators we used for evaluation. In Section 4, we respond to the above questions according to our analysis of user behavior. Section 5 concludes this paper and outlines future work.

2. RELATED WORK

Thornburg *et al.* (2014) demonstrated excellent examples in introducing 3D printing technology to the classrooms. In their book, half of 18 projects begin with 2D Inkscape drawing, and OpenSCAD is then used for 3D modeling, following the easy-to-difficult order for designing lectures.

Shneiderman *et al.* (2010) inducted the 'eight golden rules of interface design'. The second rule: 'cater to universal usability' suggested that we should provide the appropriate user interface for various user conditions. Therefore the design of a user interface has to retain a certain degree of flexibility.

Dreyfus *et al.* (1986) presented a phenomenology of skill acquisition of humans, and offered a theoretical explanation for it. Based on subjective and objective results, they presume that the learning process goes through five stages: novice, advanced beginner, competent, proficient, and expert. The process from novice to expert is universal and applicable in many fields. According to their research, we assume a model that formulates the process of skill acquisition from novice to advanced beginner, and so on, as depicted in Figure 2.

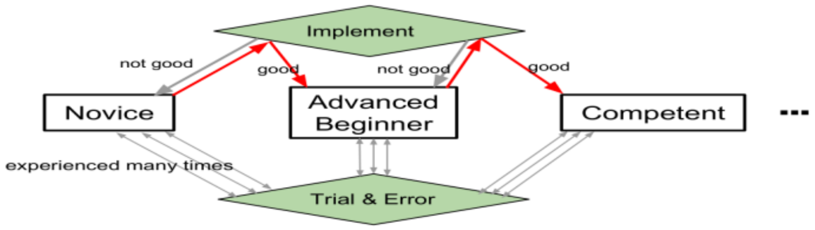


Figure 2. Skill acquisition model based on Dreyfus *et al.*'s work

3. USER LOG ACQUISITION AND ANALYSIS

This section describes the format of user logs recorded using Qmodel Creator and the subsequent analysis procedure. 3D models made by K-12 participants have been collected for experts to evaluate and judge users' competency level. Selected evaluation indicators are also presented and discussed.

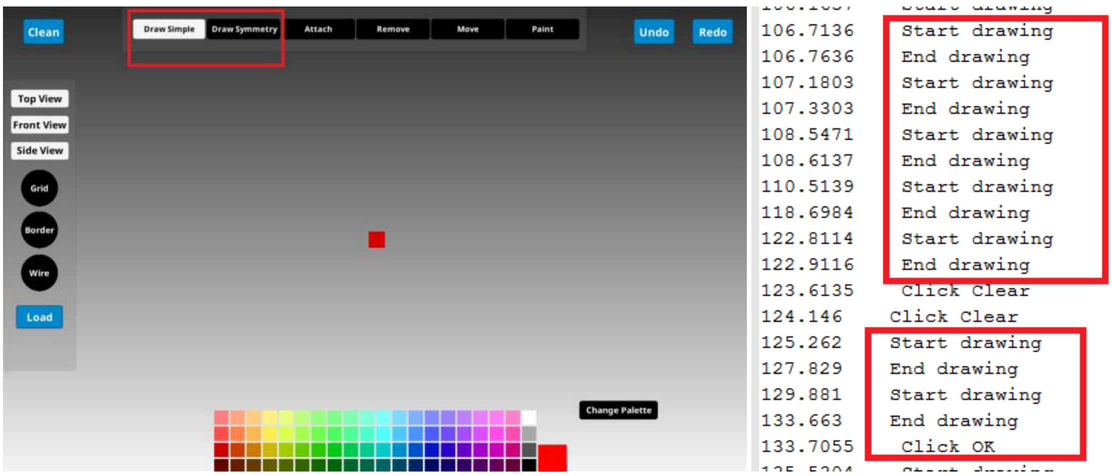
3.1 UI and Log of Qmodel Creator

Figure 3(a) shows the Qmodel Creator user interface. For all participants, we recorded each operation along with the corresponding timestamp for subsequent calculation of operation time span. We stored the information in a log file: the first field is the timestamp, and the second field is the operation event. Figure 3(b) presents a snapshot of the Qmodel Creator log file.

In Qmodel Creator, traditional 3D modeling functions such as adding and deleting voxels require more steps than intuitive modeling. Certain function keys are shared (e.g., Clean/Undo/Redo). The following list contains operations that are classified as 'intuitive'. The rest are regarded as traditional 3D operations.

- Change mode to 'Draw Simple'
- Change mode to 'Draw Symmetry'
- Start drawing
- End drawing
- Click OK

As shown in Figure 3(b), drawing operations come in pairs, with "Click OK" as the operation logged after "Adjust Thickness" and "Click Confirm".



(a) (b)

Figure 3. User interface and log of Qmodel Creator. (a) Interface; red square indicates two intuitive modeling functions: Draw Simple and Draw Symmetry. (b) Snapshot of Qmodel Creator log file. Red frame indicates intuitive operations

3.2 Data Collection

We have hosted two workshops to introduce Qmodel Creator to K-12 students and collected user logs for future analysis. The data collection processes are described below.

1. Lanyu Primary and Junior High School: The experiment involved 62 students aged from 9 to 15. The experiment was separated into three sessions. Of the 62 students, 49 used Qmodel Creator on an iPad and 13 did so using an Android tablet. In order to motivate students' interests, we prepared 3D printed models as gifts to active participants. All the students have no prior experience in 3D modeling software.

2. Sanchong High School: The experiment involved 8 students aged from 16 to 17. All the students tried Qmodel Creator on an iPad. These students have solid training in arts. They have been instructed to create 3D models using TinkerCAD and Sculptris. However, Qmodel Creator is a first time experience for them.

3.3 Users' Skill Level Identification

In keeping with the aforementioned skill acquisition assumption, there is a need for an evaluation system to gauge if the students' modeling competency for Qmodel Creator is at the novice stage. To judge the quality of 3D models in the two experiments, we designed a web interface and asked three experts (our researchers

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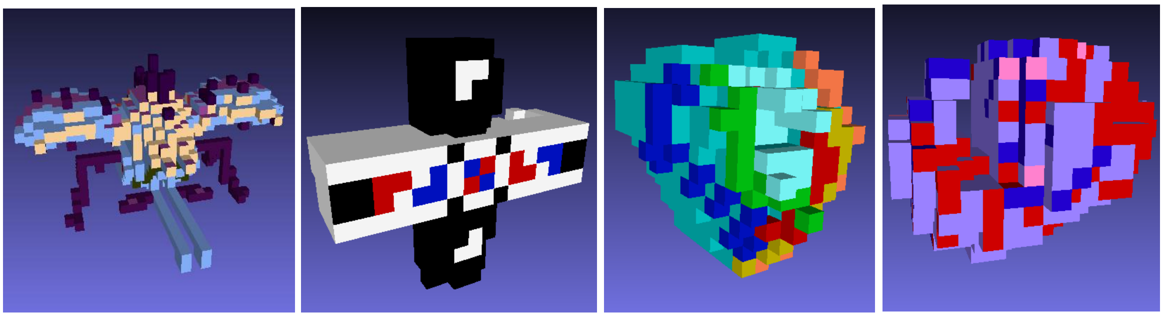
in the study) to label the model as bad or not. If a model received more than half the 'bad' votes, it was classified as a bad model. Therefore, if a model was judged as bad, the student's modeling skill was deemed to be at novice level. Figure 4 illustrates some evaluation results. The consensus rate among three experts is 82.86% (58/70).



(a) (b) (c) (d)

Figure 4. Examples of evaluation. According the votes by experts, we classified (a)(b) as advanced group, and (c)(d) are classified as novice group. (a) 0 bad vote (b) 1 bad vote (c) 2 bad votes (d) 3 bad votes

3.4 Indicators of User Behavior

To respond to the questions raised in Section 1, we propose the following indicators which can be derived from operation logs.

1. Mean and standard deviation of Step Period: In the log files, each operation has a timestamp. Therefore, we can compute the period from the previous operation to the next, thus fully reflecting the student's situation. If the student left, thus interrupting his/her operation, then the mean and standard deviation would be larger.

2. Effective Operating Period (EOP): We estimated an effective operating period that excluded daze, idle, or disturbed period, with threshold defined as 5 seconds.

3. Trial and Error Period (TEP): Operations in this period do not affect the final outcome. In log files, we check for operator "Click Clear" or "Click Undo", then label the related operators and do the calculation.

4. Implementation Period (IP): We defined the duration of a set of operations that resulted in the creation of a model as the Implementation Period. Actually, we can define Trial and Error Period, Implementation Period, and Effective Operating Period relations as Eq. (1).

$$TEP + IP + \Delta t = EOP \tag{1}$$

where Δt is the total switching cost between TEP and IP.

5. Mean and standard deviation of Trial and Error Period step: Represents an overview of a student's operating speed during the Trial and Error Period.

6. Mean and standard deviation of Implementation Period step: Represents an overview of a student operating speed during the Implementation Period.

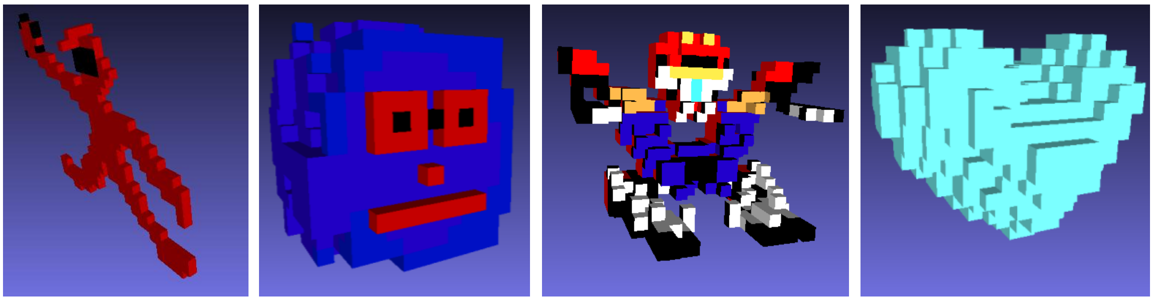
7. Degree of Detail (DoD): We discovered that if the surface to volume ratio is larger, there are more details in the model, representing a higher surface area percentage. Moreover, in order to exclude size factor, we multiply an approximate side length of the model. Thus we compute the value named as *degree of detail* as the following formula.

$$Degree\ of\ Detail = (Surface/Volume) \times (Average\ Side\ Length/6) \tag{2}$$

where *Average Side Length* is the average side length of the bounding box of the model. Using Eq. (2), a cube model with dimension N will have a DoD equal to 1.

$$Cube\ DoD = (6 \times N^2/N^3) \times (N/6) = 1 \tag{3}$$

From the above result, we know that if the DoD of a model is closer to 1, this model is more similar to a cube. Fig. 5 listed some user created models and their corresponding DoDs.



(a) (b) (c) (d)

Figure 5. Models with different *degree of detail*. (a) maximum of Lanyu: 9.81 (b) minimum of Lanyu: 1.46 (c) maximum of Sanchong: 6.61 (d) minimum of Sanchong: 1.89

Based on the above 7 quantitative indicators, the tendency to use intuitive modeling can be observed. Students were categorized into two groups with experts' evaluation of model completeness, making comparisons between groups possible.

4. RESULTS AND DISCUSSION

After defining quantitative indicators, analytic results were used to answer the questions posed in Section 1. Based on the evaluation procedure outlined in Section 3.3, of the 62 students from Lanyu Primary and Junior High School, 20 were novices while the other 42 had advanced skill. As for the 8 students from Sanchong High School, only 1 was categorized as a novice. The other 7 were categorized as advanced. Statistics of the computed indicators are summarized in Tables 1 and 2.

Table 1. Statistics of TEP, IP, EOP, DoD and intuitive operation ratio from Lanyu dataset

Gender /Age	Advanced Group											n
	TEP (s)			***IP (s)***			***EOP (s)***			***DoD***		
	Mean	***SD***	***I-r (%)***	***Mean***	***SD***	***I-r (%)***	***Mean***	***SD***	***I-r (%)***	***Mean***	***SD***	
Female	226.255	264.27	44.02	246.889	217.961	22.21	480.393	299.246	31.86	2.574	0.863	20
10	0	0	0	860.703	0	3.44	860.703	0	3.44	1.459	0	1
12	125.235	130.633	42.81	139.045	113.760	37.4	265.985	235.485	45.02	3.114	0.912	4
13	212.08	244.372	40.86	251.652	179.516	15.23	469.330	261.76	24.61	2.478	0.841	7
14	574.326	370.376	40.37	258.506	133.74	6.37	837.361	239.751	25.91	3.168	0.81	3
15	163.325	66.746	58.19	196.763	191.165	33.1	377.163	174.44	40.73	2.144	0.185	5
Male	374.27	356.160	39.73	269.195	252.103	31.62	657.111	453.428	35.57	3.822	1.764	22
9	462.108	0	73.26	197.096	0	35.17	667.905	0	62.37	4.067	0	1
10	524.143	499.9	41.08	422.832	256.818	10.47	965.773	556.165	27.48	3.32	1.2	4
12	201.532	0	38.85	251.168	0	20.22	478.078	0	27.24	3.065	0	1
13	225.255	189.515	48.59	197.165	124.130	20.28	425.808	142.094	28.96	4.427	2.73	6
14	370.339	366.052	29.83	312.392	316.138	37.46	702.954	532.925	39.26	3.801	1.308	8
15	579.74	281.478	39.06	50.289	16.931	88.53	634.448	265.078	47.61	3.352	0.127	2
Total	303.786	324.294	41.25	258.573	236.723	27.14	572.96	397.65	33.8	3.228	1.541	42
Gender /Age	**Novice Group**											***n***
	TEP (s)			***IP (s)***			***EOP (s)***			***DoD***		
	Mean	***SD***	***I-r (%)***	***Mean***	***SD***	***I-r (%)***	***Mean***	***SD***	***I-r (%)***	***Mean***	***SD***	
Female	52.962	22.805	49.68	136.636	14.692	34.07	194.977	5.8	42.44	3.024	0.169	2
12	30.157	0	39.03	151.328	0	50.06	189.177	0	49.61	3.193	0	1
13	75.767	0	60.32	121.943	0	18.07	200.777	0	35.27	2.856	0	1
Male	282.867	297.739	42.37	153.126	143.606	26.68	440.799	370.201	34.67	2.65	1.094	18
10	858.644	0	9.79	358.143	0	3.15	1219.82	0	7.81	4.834	0	1
11	319.225	15.519	48.79	259.133	241.133	45.96	583.047	256.962	41.55	3.432	0.317	2
12	321.257	352.815	65.04	170.474	105.758	14.29	497.778	370.598	38.75	2.172	0.483	6
13	109.174	142.872	24.74	97.899	115.192	20.26	211.149	252.693	28.88	2.157	0.221	6
14	446.987	245.724	52.23	100.006	74.039	41.98	551.177	170.869	43.02	2.143	0.586	2
15	117.947	0	12.15	69.608	0	93.92	192.555	0	41.39	5.751	0	1
Total	259.876	290.849	43.1	151.477	136.405	27.42	416.217	358.868	35.45	2.688	1.045	20

Table 2. Statistics of TEP, IP, EOP, DoD and intuitive operation ratio from Sanchong dataset

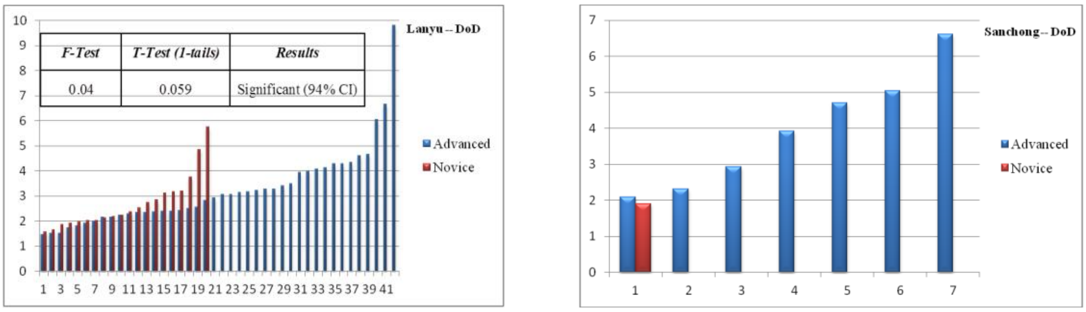
Gender /Age	Advanced Group											n
	TEP (s)			***IP (s)***			***EOP (s)***			***DoD***		
	Mean	***SD***	***I-r (%)***	***Mean***	***SD***	***I-r (%)***	***Mean***	***SD***	***I-r (%)***	***Mean***	***SD***	
Female	180.024	186.275	58.01	168.77	162.887	46.86	355.036	169.262	47.84	3.258	1.089	5
16	223.033	184.728	66.53	144.767	174.025	56.24	374.352	184.246	56.94	3.094	1.16	4
17	7.992	0	23.96	264.782	0	9.35	277.774	0	11.4	3.918	0	1
Male	52.87	24.635	53.34	57.116	24.053	62.77	110.836	0.565	65.28	5.653	0.958	2
16	77.505	0	79.88	33.063	0	58.8	111.401	0	73.77	6.611	0	1
17	28.235	0	26.8	81.169	0	66.75	110.271	0	56.78	4.696	0	1
Total	143.695	168.1	56.68	136.869	147.177	51.41	285.265	180.649	52.82	3.943	1.51	7

Gender /Age	Novice Group											n
	TEP (s)			***IP (s)***			***EOP (s)***			***DoD***		
	Mean	***SD***	***I-r (%)***	***Mean***	***SD***	***I-r (%)***	***Mean***	***SD***	***I-r (%)***	***Mean***	***SD***	
Female/16 (Total)	501.232	0	53.05	365.887	0	4.31	881.933	0	31.94	1.894	0	1

4.1 For models created with Qmodel Creator, what is the Degree of Completion?

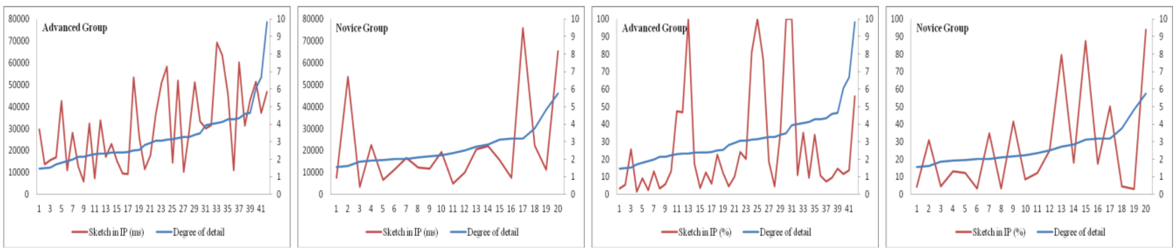
The proportion of advanced group in Lanyu dataset is 67.7%, while the proportion of advanced group in Sanchong dataset is 87.5%. It specified the degree of completion using Qmodel Creator in the two datasets. We then compared these two groups (novice and advanced) using models' degree of detail, as shown in Figure 6. We found that the models created by advanced group possessed higher degree of detail after analyzing the Lanyu dataset with F test and 1-tailed T test.

However, we were concerned that frequent use of intuitive modeling functions may affect the DoD measure. To clarify this, we compared DoD, intuitive modeling operation time and ratio during Implementation Period (IP) according to intuitive operation span defined in Section 3.1. The results are shown in Figure 7, indicating that use of intuitive modeling functions is not relevant to resulting model degree of detail, but rather dependent on the characteristics (sense or skill level) of the individual user.



(a) (b)

Figure 6. Degree of detail comparison between the different skill level groups. (a) Lanyu Primary and Junior High School, (b) Sanchong High School



(a) (b) (c) (d)

Figure 7. Comparison of relationship between degree of detail with Implementation Period of intuitive modeling using data of Lanyu Primary and Junior High School. (a) IP of advanced group in milliseconds (b) IP of novice group in milliseconds (c) IP ratio of advanced group (d) IP ratio of novice group

4.2 Which is used more frequently: Intuitive Modeling or Traditional 3D editing?

Using the conditions in Section 3.1, effective operation time span for intuitive modeling, trial and error time span, and implementation time span were calculated. As the time required for each operation is different, operation counting is not employed. Instead, we adopted operation time span, and observed the ratio of operation time span to total time span. Tables 1 and 2 show two groups of Lanyu Primary/Junior High School and Sanchong High School, as well as comparisons of ratio of those who used the intuitive modeling functions.

The results indicate that not all the students used the intuitive modeling function frequently, so traditional 3D editing functions are still necessary. However, when comparing both groups between TEP and IP in Lanyu dataset, we discovered that a considerable proportion of the users decrease the use of intuitive operation during IP in both groups, as illustrated in Table 3. Although they use intuitive modeling less in Implementation Period, the average ratio of intuitive operation of IP are more than 25%. For comparison, the average ratio of intuitive operation of IP in advanced group of Sanchong dataset is more than 50%. Therefore, high-school students who have used other modeling software and understood basic 3D space concepts use intuitive modeling functions more frequently, while primary and junior high-school students who create 3D models for the first time prefer traditional 3D editing functions.

Regarding this phenomenon, we propose a possible explanation as follows. Intuitive operations require users to have some 3D concepts beforehand in order to gain the confidence to create models in accordance with their expectation. Because Lanyu students are willing to try out unfamiliar functions, the average ratios of intuitive operations of TEP are more than 40% in both groups. However, the main purpose of this event is to submit a finished model, so the primary and junior high-school students prefer complicated but controllable operations by adding and removing voxels incrementally.

Table 3. Comparison for the ratio of intuitive operation between TEP and IP in Lanyu and Sanchong dataset

Trend	Lanyu				Sanchong			
	Advanced Group		Novice Group		Advanced Group		Novice Group	
	Count	*Ratio*	*Count*	*Ratio*	*Count*	*Ratio*	*Count*	*Ratio*
Decrease	31	73.81%	13	65%	4	57.143%	1	100%
Increase	5	11.905%	5	25%	3	42.857%	0	
No TEP	6	14.285%	2	10%	0		0	

4.3 When users create Models, is the process Smooth? Is Trial and Error needed?

We have calculated values of mean and standard deviation of Trial and Error Period step and Implementation Period step. Because the series of TEP and IP were retrieved from the same student, they should be considered as two distributions having the same variation. Thus we can adopt 2-tailed T test to examine if the operation speed were consistent during TEP and IP.

The 2-tailed T test results confirmed that the means of the TEP and IP steps were unequal, as shown in Table 4. The test results also indicated the direction of shifting means in the same tables. If the mean of IP step was sufficiently less than the mean of TEP step, then we call this case "speed up", and vice versa.

Table 4. T test significant results in Lanyu and Sanchong dataset

Trend	Lanyu				Sanchong			
	Advanced Group		Novice Group		Advanced Group		Novice Group	
	Count	*Ratio*	*Count*	*Ratio*	*Count*	*Ratio*	*Count*	*Ratio*
Speed Up	13	30.952% (13/42)	10	50% (10/20)	2	28.571% (2/7)	0	
Slow Down	4	9.524% (4/42)	2	10% (2/20)	1	14.286% (1/7)	1	100% (1/1)
Total	17	40.476% (17/42)	12	60% (12/20)	3	42.857% (3/7)	1	100% (1/1)

$\alpha=0.05$

In Table 4, we found that users in the novice group tended to speed up in Implementation Period in Lanyu dataset. This could be due to external reward or deadline pressure to complete the model-making quickly. It is suggested that these factors should be taken into account when designing lecture plans for 3D modeling.

It is worth noting that few users of Lanyu skipped Trial and Error. All cases are listed in Table 5. We also observed that some students have their own patterns of Trial-and-Error, such as using 'remove voxels' to delete content entirely. The operation counts are also included in Table 5. After excluding these cases, the remaining contained models of relatively low degree of detail, and low Implementation Period (less than 90 seconds).

Table 5. The cases of no Trail-and-Error in Lanyu dataset

Advanced Group			Novice Group		
DoD	***IP (s)***	***Remove count***	***DoD***	***IP (s)***	***Remove count***
1.459	860.703	485	2.356	40.452	0
1.507	249.554	108	2.517	39.864	0
1.976	214.154	63			
2.328	72.6	0			
3.152	14.378	0			
6.045	439.217	7			

Here, we offer several possible reasons regarding why the students skip Trial and Error, irrespective of whether they were classified as novices or advanced users:

- They are not familiar with the Clear and Undo functions, and use other buttons (e.g., remove) to purge their trial model(s). Such cases, however, still belong to the Trial and Error Period.
- They just want to finish the model quickly (e.g., to get reward).
- They have previously used similar 3D modeling applications, or have learned advanced 2D graphics software.

According to the above results, we believe that users need to be given sufficient time for trial and error. The finished models will contain more details, which means that users will have better achievements in the learning process.

4.4 How long does the User take to finish a Work?

To answer this question, we used Trial and Error Period, Implementation Period, and Effective Operating Period to evaluate the performance. In these two datasets, the longest EOP is 1,748 seconds (nearly 30 minutes), and the shortest EOP is 14 seconds. Detailed statistics have been reported in Tables 1 and 2, from which we discovered that the advanced group of Lanyu spent slightly more time to create their models than the other groups for all three sessions. Table 6 lists the F and T-test of operation periods from three user groups, namely, novice group from Lanyu, advanced group from Lanyu and advanced group from Sanchong. The result shows only the advanced group of Lanyu has a significant Implementation Period gap between the novice group of Lanyu.

Table 6. F and T test between three groups of Lanyu and Sanchong dataset

Period	***Lanyu Advanced & Lanyu Novice***			***Lanyu Advanced & Sanchong Advanced***			***Lanyu Novice & Sanchong Advanced***		
	F	***T (2-tails)***	***Results***	***F***	***T (2-tails)***	***Results***	***F***	***T (2-tails)***	***Results***
TEP	0.67	0.614	Not significant	0.14	0.217	Not significant	0.222	0.345	Not significant
IP	0.012	0.031	Significant	0.305	0.203	Not significant	0.617	0.82	Not significant
EOP	0.692	0.146	Not significant	0.075	0.072	Not significant	0.122	0.382	Not significant

$\alpha=0.05$

From above results, we can conclude that the operation of advanced group of Lanyu is significantly slower than novice group of Lanyu, suggesting that advanced group of Lanyu is more careful in creating models. Furthermore, when comparing datasets from Lanyu and Sanchong, the three periods (TEP, IP and EOP) exhibit no detectable difference. Consequently, we believe that Qmodel Creator would make an easy start for 3D model creation for all ages of K-12 students.

5. CONCLUSION AND FUTURE WORK

In this study, we investigate the usage patterns of a 3D modeling software to understand user behavior and requirements. Operation logs of Qmodel Creator have been recorded and analyzed. Characteristics of different user groups have been observed using the quantitative measures derived from the log file. The result shows that there is no significant difference in operation period between students of Lanyu Primary and Junior High School and Sanchong High School, making this software an easy-to-use tool for all K-12 students.

Designing suitable 3D modeling software for children is a challenging task. According to user behavior analysis, Qmodel Creator's intuitive modeling function greatly eases the learning curve for K-12 children. If complemented by suitable lesson plans, this software could be widely adopted by elementary school students.

We will survey other suitable 3D modeling software for the K-12 lesson plans in the near future. The quantitative indicators developed in this research could be applied to the evaluation of other 3D modeling software, as well as serve as a reference for designing lecture cases.

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