優質教育基金
Quality Education Fund

M:FR/E

Final Report of Project	**Project No. : 2016 /0255**

Part A

Project Title: To Develop Teaching Aids for Self-Paced Learning of Physics-Related topics using 3-D printers

Name of Organization/School: Department of Applied Physics, The Hong Kong Polytechnic University

Project Period: From 09/2017 *(month/year)* to 09/2018 *(month/year)*

Part B

*Please read the **Guidelines to Completion of Final Report of Quality Education Fund Projects** before completing this part of the report.*

Please use separate A4-size sheets to provide an overall report with regard to the following aspects:

1. Attainment of objectives
2. Project impact on learning effectiveness, professional development and school development
3. Cost-effectiveness – a self-evaluation against clear indicators and measures
4. Deliverables and modes of dissemination; responses to dissemination
5. Activity list
6. Difficulties encountered and solutions adopted

Name of Project Leader: _ of Grantee*:

Signature: Signature:

Date: Date:

** Final Report of Project should be submitted via "Electronic Project Management System" (EPMS). Once submitted, these reports are regarded as already endorsed by the supervisor of the school/the head of the organization or the one who signed the Quality Education Fund Agreement for allocation of grant on behalf of the organization.*

This form/guidelines can be downloaded from the QEF webpage at http://qef.org.hk.

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Attachment

Attainment of Objectives

In this project, two objectives have been proposed:

1) To develop STEM teaching aids based on 3-D printers for high school teachers.
2) To establish students' skills in basic scientific tools pertinent to physics learning through 3-D printer.
3) To enhance students' as well as teachers' competence with the use of 3-D printers as applied in science problems.

Table 1: Attainment of Objectives

Objective statement	Activities related to the objective	Extent of attainment of the objective	Evidence or indicators of having achieved the objective	Reasons for not being able to achieve the objective, if applicable
Objective 1	1) Five video modules about 3D printing have been developed in both English and Chinese version. 2) Learning and teaching materials of corresponding video were developed.	100% attained	1) The video was used by at least 3 different high schools. 25 secondary school students were recruited from a partner and two joined secondary schools in **pilot run**	
Objective 2	Questionnaires were given to different high school users for feedbacks.	90% attained	The feedbacks from both the high school teachers and students are positive.	
Objective 3	Questionnaires were given to different high school users for feedbacks.	90% attained	The feedbacks from both the high school teachers and students are positive.	

Project impact on learning effectiveness, professional development and school development

In this project, the five video modules ("Archimedes' principle", "Curved Mirror", "Centre of Gravity", "Wind Turbine" and "Optical Spectrometer") have been developed in both English and Chinese version and the L&T materials for the each module are completed (100% achieved). A pilot run in three partner secondary schools was conducted between April 2018 and July 2018 and a questionnaire was developed to collect the feedback from teachers and students. A joined workshop held in 20 June 2018 introduced our video to more secondary school. All videos are uploaded to Youtube that can be easily accessed by anyone thus enhance the publicity. A website which hosts all the materials prepared in the project, including (1) video clips, (2) 3D-printing rescore files, and (3) suggestions on adopting the materials in physics teaching.

The high school teachers can use the developed video clips, worked examples, alongside with suggested teaching plans conducing the learning for their students, following the concept of 'flipped-classroom' practices.

Cost-effectiveness – a self-evaluation against clear indicators and measures

Within the first 5 months, we have developed 2 video modules (Archimedes' principle and Centre of Gravity) and launched the video modules and 3D-printing related material. A pilot run in one partner (College) and two joined (College and School) secondary schools was conducted between April and July 2018. Based on the feedback and suggestion from users, we completed five video modules within the project period. A joined workshop held in June 2018 introduced our video to more secondary school. The stated objective for report period has been attained (with over 80% achieved).

Table 2: Budget Checklist

Budget Items *(Based on Schedule II of Agreement)*	**Approved Budget (a)**	**Actual Expense (b)**	**Change [(b)-(a)]/(a) +/- %**
Staff	144,585.0	130,592.9	-9.68%
General Expense	5015	5000	-0.30%

Deliverables and modes of dissemination; responses to dissemination

A website (http://ap.polyu.edu.hk/apshchoy/qef_project_2016_0255.html) which hosts all the materials prepared in the project, including (1) video clips, (2) 3D-printing rescore files, and (3) suggestions on adopting the materials in physics teaching, was developed and the screen captures of the developed webpage were shown in Figure 1. Figure 2 shows the screen captures the video clip "Trigonometry".

Figure 1 Screen captures of the developed webpage.

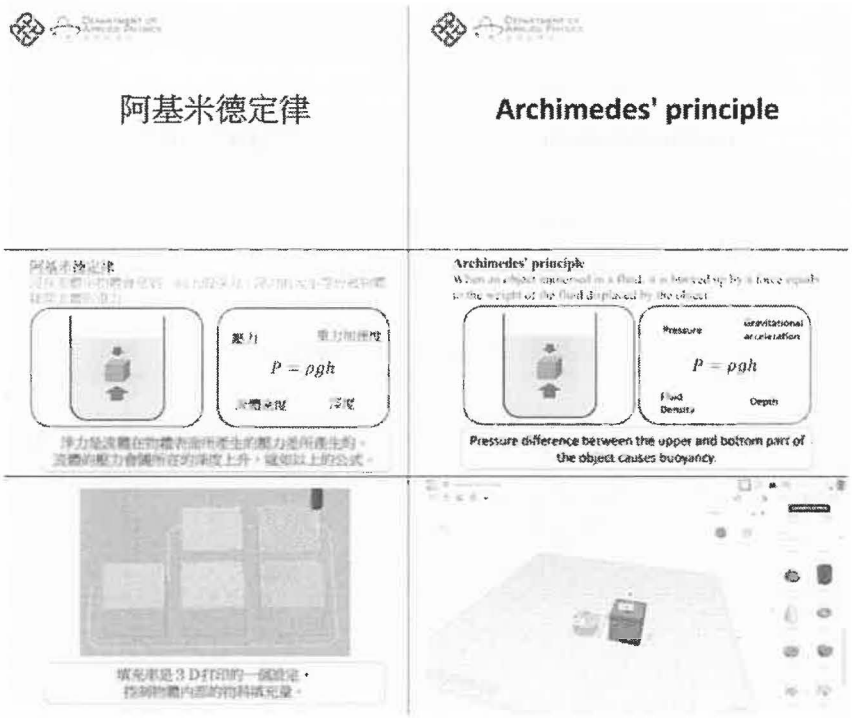

Figure 2 Screen captures of the video clip of "Archimedes' principle" (English and Chinese versions).

Students and teachers can view the video clips on the developed website or on Youtube platform. Publish the video clips on Youtube platform will have a better publicity in this project and students can be easily accessed by smartphone applications which may enhance their learning experience. Table 1 summarized all the video links on Youtube and related 3D-printing resource materials with corresponding QR code for easy access.

Table 1 Summary of video links on Youtube and related 3D-printing resource materials with corresponding QR code.

English Version	中文版本	
Archimedes' principle https://youtu.be/2F42u6V1vfE	阿基米德定律 https://youtu.be/QioH9U-euL8	Supporting Materials https://goo.gl/M4NZ2v

Curved Mirror https://youtu.be/HrK00smJ_AM	曲面鏡 https://youtu.be/G1hIKCVIDUU	Supporting Materials https://goo.gl/Asw5fJ

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Centre of Gravity https://youtu.be/p49gy1J0eWs	重心實驗 https://youtu.be/9QcFqpJxurg	Supporting Materials https://goo.gl/jmxcrv
Wind Turbine https://youtu.be/o4YDv7angX8	風力發電機 https://youtu.be/xgAxggODLdo	Supporting Materials https://goo.gl/NA75Hu
Optical Spectrometer https://youtu.be/E8nuMfRjIds	光譜儀 https://youtu.be/S-VjzTleAIs	Supporting Materials https://goo.gl/C6sbVe

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Table 3 Dissemination Value of Project Deliverables

Item description (e.g. type, title, quantity, etc.)	Evaluation of the quality and dissemination value of the item	Dissemination activities conducted (e.g. mode, date, etc.) and responses	Is it worthwhile and feasible for the item to be widely disseminated by the QEF? If yes, please suggest the mode(s) of dissemination.
A platform (webpage and Youtube) for Short Video Clips for Self-Paced Learning of Physics-Related topics using 3-D printers	1. Focus Group Interview Report and questionnaire.	A pilot run in one partner (College) and two joined (and School) secondary schools was conducted between April and July 2018.	

The Effectiveness of 3-D Printing Programme on Students' Learning

This study is to investigate the impact of 3-D Printing Programme in usefulness of teaching materials, competence in using 3-D printer and whether knowledge in science is enhanced. Several ways were used to evaluate.

I. Methodology

Twenty-five participants aged within 12-16 years old were recruited from three secondary schools. There were 21 male (84%) and 4 female (16%). Two-third of them study in Physics.

Participants were committed a 1 week 3-D Printing Programme. A pre-test assessing concept of centre of gravity (CG) and spatial ability (SA) was administered before delivering teaching material including notes and videos. Then, teaching materials were distributed. The video is divided into three parts, (i) introduction of CG; (ii) how to draw a 3-D model; and (iii) experimental procedure. After watching the video, students learnt to draw a 3-D diagram via an online platform, TinkerCad. They drew at home and submitted to their teacher. 3-D models were then printed by school. Finally, experiment, post-test and feedback survey were conducted on a school day.

II. Results and Analysis

2.1 Pre-test and Post-test

In the pre-test and post-test, concept of CG and SA are included. There are ten and twelve multiple choice questions respectively. Their full marks are 10 and 16. Descriptive statistics and paired sample *t*-test were performed to examine the effectiveness of 3-D Printing Programme. All the analyses were conducted using SPSS 23.

According to Figure 3, there is one extreme outlier with asterisk that values more than three times the interquartile range from a quartile. It was removed for further analysis.

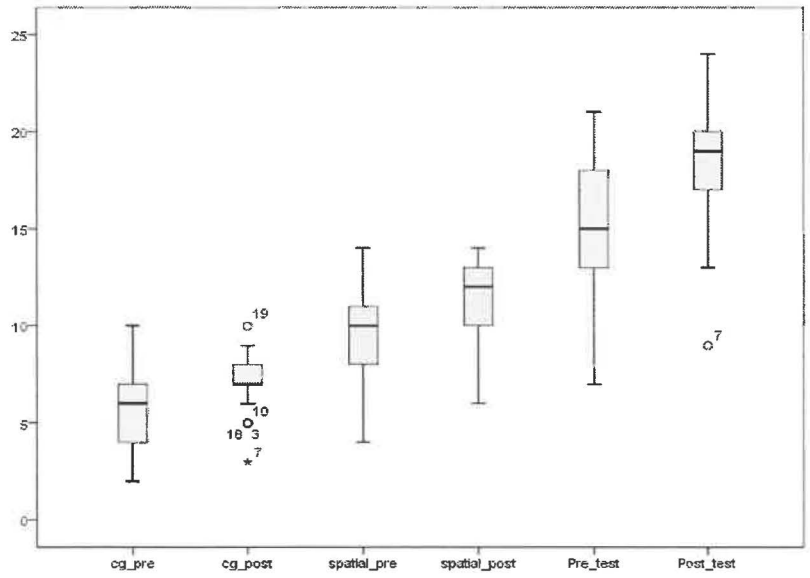

Figure 3. Boxplot of students' performance in pre-test and post-test

As displayed in Table 4, there are statistically significant differences, at the .05 significance level, in pre-test to post-test scores for concept of CG ($t(23) = -3.72$, $p = .001$), SA ($t(23) = -3.19$, $p = .004$) and overall ($t = -5.68$, $p < .001$). Results show that students performed better in post-test after the 3-D Printing Programme. This programme is likely to have positive effect to student in both concepts of CG and SA. Students' knowledge on science and generic skills were developed.

Table 4

Descriptive Statistics and paired sample t-test Results for concept of CG, SA and overall.

	Pretest		Posttest			95% CI for Mean			
	M	SD	M	SD	n	Difference	r	t	df
CG	5.83	2.10	7.33	1.40	24	-2.34, -0.66	.42*	-3.72*	23
SA	9.54	2.77	11.42	2.26	24	-3.09, -0.66	.36	-3.19*	23
Overall	15.25	3.60	18.75	2.82	24	-4.78, -2.22	.58*	-5.68*	23

* $p < .05$.

2.2 Feedback Form

There are 18 likert-type items from 1 (Strongly Disagree) to 5 (Strongly Agree) with three reversed questions and one open-ended question to understand students' views on learning and teaching (L&T) materials; learning experience and outcome; as well as overall comment. Twenty-three responses were collected. Items 3, 5 and 11 have already been reverse coded for analysis and discussion. Most respondents showed positive feedback and chose '3-Neutral', '4-Agree' and '5-Strongly Agree' ranging from around 80% to 100% as shown in Figure 4.

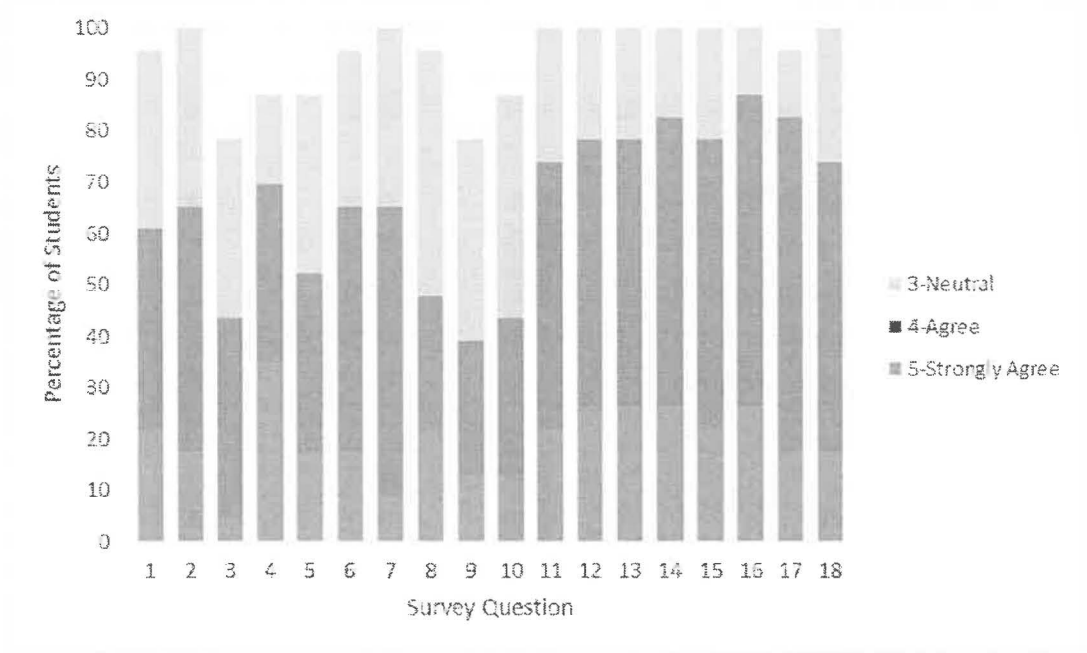

Figure 4. Student feedback on 3-D Printing Programme

Mean of all items are above three. Three items obtain highest marks are item 16 (M = 4.13, SD = 0.63), 14 (M = 4.09, SD = 0.67), 12 and 13 (M = 4.04, SD = 0.71). Students agreed that they have completed all tasks successfully. They could learn at their own pace with the new L&T method, flipped classroom and the activity was creative to them. Also, they agreed 3-D printing allow them to develop their creativity with drawing 3-D diagram and printing the product.

Alternatively, three lowest scoring items are 3 (M = 3.17, SD = 1.03), 9 (M = 3.22, SD = 1.13) and 10 (M = 3.35, SD = 1.07). Although the item about the appropriateness of video's length obtained the lowest score, it is still above 3. Students are fine with the length of video, which is not too long. Students reflected that they were not satisfied in operating 3-D printers and developing own design, which may be due to the operation was mainly conducted by teachers or technicians and students observed the procedure only.

Table 5 *Descriptive Statistics of Survey in Course Satisfaction*

Survey Question	*M*	*SD*	*N*
Part I: Learning and Teaching Materials			

1. Videos are easy to follow and understand.	3.78	0.85	23
2. Teaching materials (both lecture notes and videos) are useful for learning.	3.83	0.72	23
3. *Videos are too long.	3.17	1.03	23
4. The software is easy to access.	3.91	1.04	23
5. *The software is difficult to use.	3.52	1.04	23
Part II: Learning Experience and Outcome			
6. I engage more in watching videos than traditional classroom instruction	3.78	0.80	23
7. Re-watching videos help me understand difficult concepts better.	3.74	0.62	23
8. I like learning through watching videos	3.65	0.88	23
9. I can operate 3D printer on my own.	3.22	1.13	23
10. I can develop my own design with 3D printers.	3.35	1.07	23
11. *I am helpless in printing 3-D models.	4.00	0.71	23
12. 3D printers allow me to develop my creativity.	4.04	0.71	23
Part III: Overall			
13. I can learn at my own pace.	4.04	0.71	23
14. I completed all tasks successfully.	4.09	0.67	23
15. I am motivated to explore content related questions.	4.00	0.67	23
16. The activity is creative to me.	4.13	0.63	23
17. I would recommend this programme to others.	4.00	0.71	23
18. I am satisfied with this learning experience.	3.91	0.67	23

*Reverse coded

2.3 Focus Group Interview

Two focus group interviews were conducted on 6 and 12 July 2018 at two secondary schools. There are 14 students in total. They discussed their views on flipped classroom, 3-D drawing and printing and the overall programme.

Flipped Classroom

Most of them (70%) were new to flipped classroom. They commented this novel L&T method was student-centered and more interesting than traditional classes. They were motivated in self-regulated learning. They could learn at home with high degree of freedom, at their own pace and re-watch videos to understand difficult concepts. However, the drawback is longer time is needed for exploration. It would be good if there is higher participation of teachers such as discussion forum.

They enjoy this learning process; they found that they learn more and deeper when they have

activities with teacher's guidance after preparing at home. Memory of video and knowledge were recalled when they conducted experiment. Thus, they learnt in a more impressive way. Also, they suggested having assignment at home before class such as designing how to conduct experiment and change the shape of product. They were motivated to explore content related questions.

Teaching Materials

Students agreed that there are plenty of resources. They love learning through watching video instead of reading textbook as video is more attractive. The video is comprehensive and easy to follow. However, videos could be improved if there was narrator and explaining in more details. Also, more descriptions such as clicking the button, parameter, ratio… are needed. Some students suggested to add interactive questions into the videos. They could continuous watching video if they answered correctly, otherwise explanation would be shown. In addition, students showed interest in online learning. They expressed it is common to learn mathematics or English through APPs and watching videos about programming in YouTube today. Probably, it becomes a trend in new generation and opportunities in education.

3-D Drawing and Printing

Students started to make a 3-D product includes drawing 3-D diagram and using 3-D printers on the next stage. However, the operation of 3-D printers was mainly operated and demonstrated by teachers and technicians due to limited time and resources. Students focus in the design of 3-D figures. They commented the online platform is convenient and user friendly. The platform was interesting though it was challenging that several hours were used to explore. They suggested having a video to introduce the platform. At the end, they felt sense of accomplishment to design their own product and saw the unique printed object.

Overall Comment

In short, there are lots of positive feedback and have given students a new learning experience. They were relaxing and happy in learning. They were surprised to change the shape of 3-D model. They mentioned the workshop was not boring. There were interactions, students could move around and learning by doing compare with traditional L&T method. Overall, using technology of 3-D printing is innovative. They have learnt better through the programme with printed objects rather than reading from the textbook only. They understood the scientific concepts more and imagination and creativity were developed, which is useful in the future. Even some did not study Physics, their motivation and interests in learning science were enhanced.

III. Conclusion

Several evaluations were conducted. Pre-test and post-test were administered to analyze students' performance. Students improved significantly in both scientific knowledge and spatial ability after the programme. With the support of survey and interviews, students were positive to the 3-D Printing Programme. They commented that they learnt better and scientific knowledge was more impressed than in traditional class. They were motivated by the novel L&T method, flipped classroom. They enjoy learning by watching videos and preparing themselves for the experiment, which is more student-centered with flexible

schedule. Moreover, they love the interaction with instructor during experiment.

For spatial ability, past researches have demonstrated spatial skills are malleable, which can be improved through trainings at different stages throughout the lifespan (Uttal, Meadow, Tipton, Hand, Alden & Warren, 2013). We studied if indirect training such as 3-D drawing that involves spatial processes improves spatial ability of students. The results reported students improved significantly after the programme. This ability is important for success in solving tasks in daily life and many fields of professional such as natural sciences, engineering and architecture. Therefore, relationship between technology and cognitive processes is worthy to be further studied.

Overall, students were satisfied with this programme (M = 3.91, SD = 0.67) and would recommend to others (M = 4.00, SD = 0.71). They expressed the programme was innovative and their creativity was developed. Also, they suggested having more interaction with teachers such as discussion forum to assist in drawing 3-D diagram. Videos could be made clearer with narrator and more interactive by adding questions. H5P (https://h5p.org/) is one of the options to develop interactive videos in the future. To conclude, experiential learning with aid of technology becomes prevalent in Hong Kong Education. In order to develop a good environment in online and self-regulated learning, transactional distance proposed by Moore (1993) with three main factors, dialogue between instructor and students; rigidity or flexibility of course structure and learner autonomy, are suggested to be considered in programme design in the future.

Reference

Moore, M. G. 1993. 1993. Theory of transactional distance. In *Theoretical principles of distance education*, vol. 1, ed. D. Keegan, 22–38. New York: Routledge Chapman & Hall.

Uttal DH, Meadow NG, Tipton E, Hand LL, Alden AR, Warren C, Newcombe NS. 2013. The malleability of spatial skills: a meta-analysis of training studies. *Psychol Bull 139(2):*352–402

Activity list

Types of activities *(e.g. seminar, performance, etc.)*	**Brief description** *(e.g. date, theme, venue, etc.)*	**No. of participants**				**Feedback from participants**
		schools	teachers	students	others (Please specify)	
Pilot- run of video modules	April 2018 - July 2018, partner school and joined schools	3	3	25		The general feedbacks from the students and teachers are very positive.

A the joined QEF workshop of "Use of e-Resource to Facilitate the Understanding of Mathematical Concepts of Students in Learning Physics"	20th June, 2018 in Room CD620, The Hong Kong Polytechnic University	>10	>20	Nil	members of science education sections, CDI,EMB.	The comments from the teachers are positive.

Difficulties encountered and solutions adopted

Nil