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The Design and Implementation of a Video-facilitated Transdisciplinary STEM Curriculum in the Context of COVID-19 Pandemic

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ABSTRACT: The COVID-19 pandemic has brought disruptions and constraints to K-12 STEM education, such as the shortened classroom time and the restrictions on classroom interactions. More empirical evidence is needed to inform educators and practitioners which strategies work and which do not in the pandemic context. In response to the call for more empirical evidence and the need for cultivating responsible and competent 21st century citizens, we designed and implemented a transdisciplinary STEM curriculum during the COVID-19 outbreak. In order to facilitate the smooth delivery of the learning contents and authentically engage learners in the learning process, multi-model video approaches were employed considering the characteristics of three disciplines, STEM, social service, and writing, as well as learner diversity. Pre- and post-test results indicated that students' transdisciplinary STEM knowledge improved significantly after completing the curriculum. The integration of STEM, social service, and writing disciplines promoted the growth of students' empathy, interest, and self-efficacy. Consistent with the quantitative results, students responded in the interview that their STEM knowledge and empathy were both enhanced. Some implementation strategies introduced in the current study are also applicable when the standard teaching order is restored in the post-COVID-19 era.

Keywords: STEM, Transdisciplinary STEM, Video-facilitated approach, Social service, Empathy

1. Introduction

Due to the COVID-19 outbreak, over the world, students are unable to attend schools as per the previous norm. Consequently, emergency education is put into practice in many countries (Bozkurt et al., 2020). To reduce the loss of curriculum time, the Hong Kong Education Bureau has requested all subjects to make a series of adjustments to standard scheduling procedures. In the context, the implementation of transdisciplinary STEM education faces many challenges, such as the reduction of course capacity due to the shortened classroom time, and limited classroom interactions for maintaining social distance. In response to the emergency, many STEM disciplines moved to online learning and used video-based learning approaches to ensure content delivery. For example, in the United States, the urology residents training was changed from didactic sessions to video-based online sessions (Tabakin et al., 2021). In other universities, instructors used pre-class video sections to prepare Chemistry students for subsequent synchronous Zoom lectures (e.g., Lapitan et al., 2021). However, empirical studies examining the effectiveness of the video-facilitated instructional approach in the pandemic chiefly centered on the higher education sector. At the K-12 level, there is a clear emphasis on knowing how to organize STEM courses smoothly in the COVID-19 context. It is essential to know how STEM was carried out during the pandemic, what impacts it achieved, and what lessons can be learned.

Currently, at the K-12 level, there are several studies examining student and parent perceptions on distance learning regarding the adequacy of online learning materials (e.g., Chang et al., 2020; Fiş Erümit, 2020), the collaboration styles during homeschooling (e.g., Yates et al., 2020), and teacher perspectives on technology-enabled remote learning (e.g., Ewing & Cooper, 2021; Jong, 2019a). These studies enabled us to understand, at the macro level, what worked in emergent distance education and what needs to be improved. Nevertheless, in terms of specific K-12 disciplines, the collected empirical evidence is insufficient. Not to mention transdisciplinary STEM, which needs the collective efforts from multiple domain experts.

Transdisciplinary STEM refers to the production of new perspectives and solutions to problems by drawing upon multi-discipline knowledge and skills (Gibbs, 2015). Many problems in the natural world are complex and could not be solved with knowledge from a single discipline. Hence, drawing on the expertise of multiple disciplines can assist in developing a more comprehensive understanding of the situations and create new possibilities for solutions (Quigley et al., 2019). In K-12 STEM education, it is widely agreed that empathy, care, and STEM education should be integrated to cultivate 21st-century citizens who would develop socially responsible and environmentally sustainable solutions (Rulifson & Bielefeldt, 2017; Gunckel & Tolbert, 2018). Lee and Campbell (2020) proposed an instructional framework advocating the use of science and computer science content related to COVID-19 to engage K-12 students in understanding the phenomena and solving societal problems. Several studies made efforts to integrate STEM education with the element of empathy (e.g., Hutchison, 2016). However, to the best of available knowledge, none of them examined the effectiveness of using a video-facilitated approach to ensure the continuity of transdisciplinary STEM education in the COVID-19 context.

This study aimed to design a video-facilitated transdisciplinary STEM curriculum and test its effectiveness in a secondary school. It is intended as an empirical reference to the implementation of transdisciplinary STEM during the pandemic. In addition, the video-facilitated approach in this study is generalizable to other STEM courses when standard teaching order is restored in the post-COVID-19 era because the difficulties discussed in this paper (e.g., catering to individual learner differences) exist in both normal and non-normal learning settings in STEM education (Epler-Ruths et al., 2020; Jong, 2019a; Jong et al., 2020).

The research questions are:

- In the COVID-19 context, what is the impact of the video-facilitated transdisciplinary STEM curriculum on students' factual knowledge?
- In the COVID-19 context, what is the impact of the video-facilitated transdisciplinary STEM curriculum on students' design competence?
- In the COVID-19 context, what is the impact of the video-facilitated transdisciplinary STEM curriculum on students' empathy, self-efficacy, and interest?
- In the COVID-19 context, what are students' perceptions of the video-facilitated transdisciplinary STEM curriculum?

2. Literature review

2.1. Transdisciplinary STEM learning

Transdisciplinary STEM applies knowledge and skills learned from two or more disciplines to real-world problems and contributes to an active learning experience (Vasquez et al., 2013; English, 2016). There has been a rising call to emphasize connections between disciplines in STEM education (Chai et al., 2020; Geng et al., 2019; Honey et al., 2014; So et al., 2020). For example, in the United States, the STEM Task Force Report (2014) emphasized that STEM education is not a convenient integration of four disciplines, but the incorporation of real-world problem-based learning that connects the disciplines through coherent and active teaching and learning practices. Many scholars believe that the best preparation for students' future careers must involve interdisciplinary thinking (Quigley et al., 2019). Having STEM taught in a more connected way and set in the context of real-world problems will make STEM subjects more beneficial to students. This practice could lead to increased motivation, improved achievements, and higher persistence (Honey et al., 2014). In turn, these outcomes will help meet the call for a robust workforce (Linnenbrink-Garcia et al., 2016).

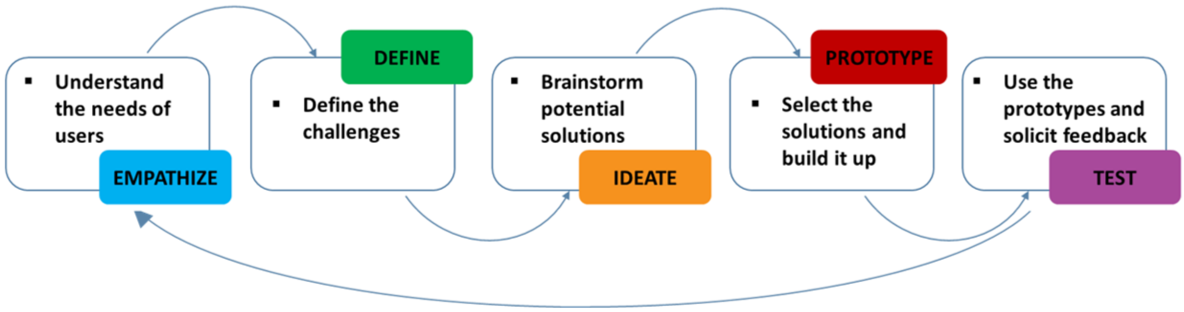
However, it is more common to integrate two or more science-related disciplines in STEM education rather than integrating science with disciplines from social science. For example, Hong et al. (2019) integrated scientific inquiry, mathematical thinking, and design technology into a college-level STEM course and promoted learning through a knowledge-building forum. They found that students demonstrated their competence in designing and improving designs in the knowledge-building environment. The study contributed to our knowledge of a practical approach for enhancing STEM learning, but it did not cover the social science discipline. Maiorca et al. (2021) studied the impacts of an interdisciplinary summer school project. The project combines science, education, medicine, and engineering to give Grade 5 to Grade 8 students authentic and hands-on STEM learning experiences. They found that this program enhanced students' self-efficacy and interests. While there are many socio-scientific issues, such as various forms of pollution and fighting the pandemic, which requires an integrated understanding of STEM and humanities, few studies integrate the two fields (Gunckel & Tolbert, 2018).

2.2. Theoretical framework for STEM curriculum design

To foster connections between STEM and humanities, the design thinking framework proposed by the Hasso Plattner Institute of Design at Stanford University is a reasonable choice. Beginning with empathy, the framework naturally draws on disciplines such as social studies to identify problems that confront humanity. Empathy is also a psychological construct that could motivate students to learn engineering knowledge (e.g., Chai et al., 2020). Grounded in emphatic understanding, designers then define the problems, ideate, prototype, and test (Hasso Plattner Institute of Design [HPID], 2010). For simplicity, we refer to the design thinking model as EDIPT. The EDIPT model is widely accepted in the design and STEM education fields. It advocates the necessity to understand users' potential needs with an empathic mind, and then work out solutions to cater to the needs. When needed, subsequent improvement of the prototypes is processed based on feedback from the users. Liedtka (2018) commented that the organized design process of the EDIPT model could help innovators carry out design processes in a more systematic manner and provide them with a sense of psychological safety to experiment.

As depicted in Figure 1, there are different focuses in the five phases of the EDIPT model. In the empathy phase, students visit users and talk with them to understand their potential needs. In the definition phase, students can synthesize and select the needs they consider important to fulfill, and then identify the one they will focus on in their design. In the ideation phase, learners propose a range of possible solutions to choose from by applying divergent thinking. Students build a prototype of the solution to bring them closer to their final solution in the prototype phase. In the testing phase, students demonstrate the prototype to users to collect feedback and further refine the solution. Simeon et al. (2020) applied the EDIPT model in a secondary school to promote the learning of physics concepts and found that both female and male students improved their achievements in physics at the completion of the course. Morrin and Liston (2020) implemented the EDIPT model in a STEAM project where arts and design thinking were promoted involving pre-service and in-service teachers and elementary school students. The project generated positive impacts on the attitudes and competencies of the teachers and students. These outcomes demonstrate that the EDIPT model is appropriate for scaffolding the design of secondary school STEM courses. Echoing the cross-disciplinary calling for the combination of technology and human-centeredness, we designed an integrated curriculum that builds on three subjects, STEM, social service, and writing, the latter of which has been less studied in the literature.

Figure 1. EDIPT Model and key procedures adapted from HDIP (2010)



2.3. Video-facilitated learning approach

Educational videos have become important content delivery tools for K-12 and higher education with their widespread application in flipped, blended and online courses (Brame, 2016; Jong, 2019b; Lin & Chen, 2019). Video lectures often allow students to fully comprehend the course material by allowing them to playback the video content as often as they need to, thus catering to students' individual differences (Brecht & Ogilby, 2008; Chen & Wu, 2015; Song et al., 2017). The advantages of video are substantial, such as (1) demonstrating the procedure for using a tool or equipment; (2) presenting the dynamics of a change or principle of motion; (3) replacing field trips with precise visual images of a scene and giving or providing students with a sense of immersion or facilitating a sense of student immersion; and (4) increasing the interest of the course by connecting it to real-world problems (Bates, 2019). Furthermore, a subset of video-based learning, the flipped learning approach, is beneficial to learning in a number of ways (Bond, 2020). The pre-class videos could free up in-class time for learning (Lo & Hew, 2021), potentially reduce the perceived course difficulty by introducing relevant concepts before class (Bond, 2020), and empower students to take ownership of their learning (D'addato & Miller, 2016). To ensure the effectiveness of video designs, Brame (2016) recommended three principles to follow: managing cognitive load, maximizing student engagement, and promoting active learning. According to Brame (2016), adding signal words or colors to highlight important information, keeping the video brief, using conversational language, and using guiding questions are effective strategies in engaging students.

In STEM subjects, video-based learning approach is often adopted to facilitate learning. Lo and Hew (2021) applied video-based flipped learning in middle school mathematics courses and found that students achieved significantly higher learning gains than the class without pre-class videos. Students in the video-based learning group also reported that the pre-class video boosted their confidence in the in-class problem-solving session. Similarly, Tsai et al. (2020) used pre-class videos in a middle school civic education class and reported that the videos promoted students' performance and learning motivation. Jong et al. (2020) compared the video-based virtual reality approach with the traditional textbook-based approach, and found that the video-based virtual visits to natural environments enabled students to connect knowledge to authentic contexts and achieve better learning outcomes.

In the context of COVID-19 and the resultant closure of many schools, countries and regions are using educational videos as one of the primary tools for content delivery (Pal & Patra, 2020). In Algeria, for example, the ministry of education has launched a YouTube channel and uploaded curriculum-related videos for K-12 students to study at home (Bozkurt et al., 2020). In the UK, Conlon and McIntosh (2020) found that student nurses perceived videos demonstrating scenarios held more authenticity and social relevance than digital audio and photobook styles. In Malaysia, pre-recorded lectures and hands-on training sessions were used for medical physics education during the partial lockdown. Students reported that short videos with questions helped them understand the topics better than the lengthy ones (Azlan et al., 2020).

Building on the experiences shared by scholars and researchers, we designed the video-facilitated instructions for students of the STEM curriculum. Since this is a transdisciplinary course and each course has unique characteristics and roles, we designed the video strategy based on each course's characteristics. The design will be described in the methods section.

3. Methods

3.1. Design of the video-facilitated transdisciplinary STEM curriculum

The transdisciplinary curriculum design is informed by the notion that integrating STEM and social studies provides an authentic context for problem-solving. Authentic problems such as the difficulties faced by visually impaired people in daily life were presented to students. To resolve these problems, students need to draw on their existing knowledge from multiple disciplines, such as user needs, materials, product design, tools and platforms. The design followed the process in EDIPT model (HPID, 2010). The prototype and test stages were delayed with a written proposal and presentation, where students presented their ideas verbally and collected feedback from experts and peers. The progression from "empathize" to "feedback" should help students understand the basics of designing a user-centered solution. In writing the proposal, students learn the language knowledge and skills for presenting the design solution proposed in the social service course. Additional content covered in the STEM course includes the fundamentals of electronic circuits, coding through Blynk and Thunkable, and the Internet of Things (IoT). Table 1 illustrates the main contents covered in the curriculum. Figure 2 depicts the in-class STEM activities.

Table 1. Contents of the transdisciplinary STEM curriculum

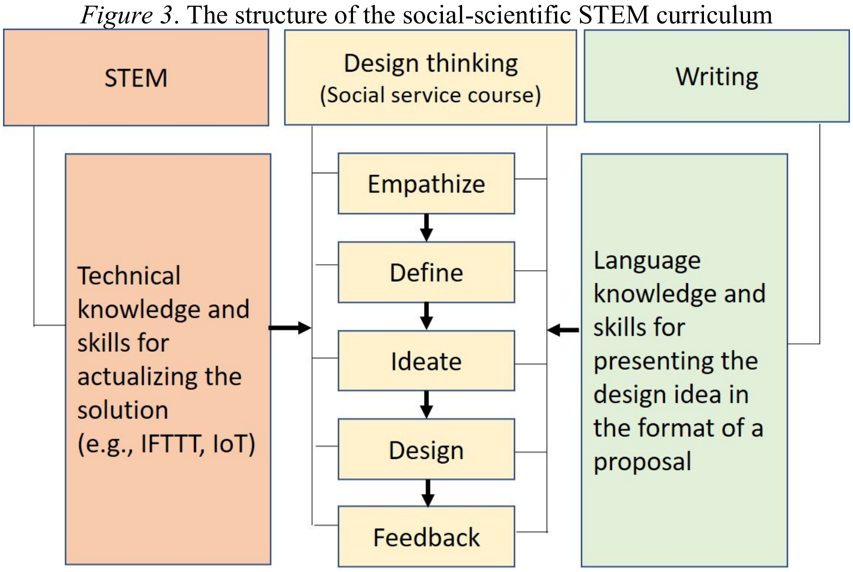
Discipline	Duration	Main purpose	Main contents/ Topics
STEM	6 weeks (1 hour/lesson)	Technical knowledge and skills	(1) Basic coding skills and computational thinking. (2) Basic IoT concept and applications (1). (3) Basic IoT concept and applications (2). (4) IFTTT and Smart Home Device. (5) Project-based Learning: Maker Education. (6) Mini Project on STEM Education.
Social service	5 weeks (1 hour/lesson)	Design thinking process & background knowledge	(1) Basic understanding of social services. (2) Basic knowledge of the user group and services provided by social service organizations. (3) Basic concepts and skills for developing a product for the user group. (4) Video-based field visit and (deeper) understanding of user needs. (5) Presentation of initial solutions and feedback from experts and peers.
Proposal writing	3 weeks (30 mins/lesson)	Language knowledge and skill	(1) Introduction of proposal content and wording. (2) Writing a proposal for the sample product. (3) Writing a proposal for students' own design solutions.

Figure 2. In-class STEM activities

STEM teacher teaches class through live broadcast | Students work on the hands-on sessions in-class | Sample student coding work on Thunkable

The curriculum implementation consists of two stages. The first stage was described above. The second stage involves prototyping and testing the solution. Due to the pandemic, students needed to maintain social distance, and could not work close to prototype products. The prototype creation and testing would be carried out when social-distance restrictions are eased. Hence, we are reporting the implementation and outcomes of the first cycle. See Figure 3 for the design of the first stage transdisciplinary curriculum.

Figure 3. The structure of the social-scientific STEM curriculum



In terms of the organization of teaching activities, we considered several issues, such as

- The shortening of teaching time since only half-day classes can be conducted.
- The social distancing and the unavailability of group work in class make learning more challenging for individual students.
- The student diversity (e.g., different speeds in coding) should be addressed.

In response to these challenges, a series of alternative video-facilitated strategies have been adopted. The level of student engagement with videos differs across course styles (Guo et al., 2014). Hence, we tailored the video strategies for each course accordingly. In the STEM course, short videos of less than three minutes were provided for students to preview before class. Introducing concepts before lessons can increase the active learning time in class (Lo & Hew, 2021). The length of the pre-class video was purposely shortened to make it more engaging (Azlan et al., 2020). For the hands-on sessions, all procedures were pre-recorded so that students could watch the video while working to offset the problem of not maintaining pace with the instructor during the class. Students can pause and revisit the video in their own time as required (Yates et al., 2020), and reduce their perceived course difficulty (Bond, 2020). Upon completing a hands-on section, students would take a picture of the completed work and upload it to Google classroom. Then, in the social service classroom, students watched the field visit video and completed the questions on the worksheet. Though virtual field visits may not be as informative as actual field visits, they can add variety to the learning experience and enhance authenticity (Chang et al., 2020; Friess et al., 2016). The video-based field visits were intended to make the topic more approachable and help students gain a deeper understanding of the context (Conlon & McIntosh, 2020; Jong et al., 2020). See Figure 4 for the typical video approaches applied in the study. Table 2 introduces the educational purposes of the approaches. Details of the video-facilitated strategies in the COVID-19 context are illustrated in Appendix I.

Figure 4. Screenshots of typical video-assisted approaches adopted in the study

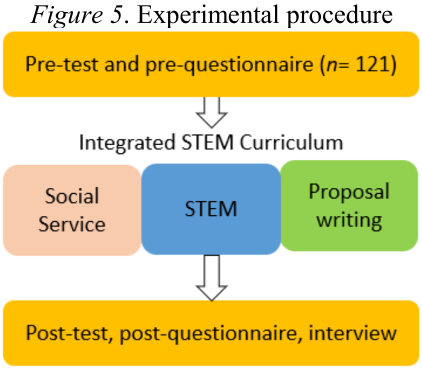
Table 2. The video approaches and educational purposes

	Video approaches and educational purposes
STEM	(1) Pre-class short videos: To introduce the basic concepts of each topic. (2) In-class video of hands-on sessions: To attend to learner differences and make sure learners with different learning paces can keep up with operation progress. *Note.* The length of each video was less than 3 minutes. Videos longer than 3 minutes were split into several clips.
Social service	(1) In-class video of field visit: To provide students with a sense of authenticity and make connections between learning and real-world problems. To provide students access to gain a close understanding of the needs of users (e.g., the visually impaired group) (2) Post-class video of extension videos. To provide students with access to know more assistive technology tools. *Note.* The in-class video was filmed before class by the project team. It presented the interview between the project team, several visually impaired people, and the social workers in the social service organization. Guiding questions on worksheets were assigned to students in class.
Proposal writing	(1) In-class video of an exemplar product's development background: To provide a sense of authenticity and link learning with real-world examples. To introduce the back story of an assistive technology tool. (2) In-class video of product demonstration: To introduce the aspects to be included in a product proposal. *Note.* Guiding questions were assigned to students in class.

3.2. Participants

To examine the effectiveness of the curriculum, we conducted a single group pre- and post-test experiment. It tracked the changes in students' transdisciplinary STEM knowledge, empathy, self-efficacy, and interest after completing the course. In addition, interview results with students were analyzed to triangulate the data. In total, 121 students gave consent to participate in the research. Their ages were between 12 and 14. The participants were from four classes of Grade 8 in a secondary school. Among them, 49 were females, and 72 were males. As illustrated in Appendix I, one STEM teacher taught four classes simultaneously via live streaming. At the same time, each class was accompanied by an experienced teacher and a student mentor to support students on-site. All the learning materials, such as hands-on practice videos and e-handouts (i.e., steps of the hands-on session and the flow of the course), were released to students before class on Google classroom. The experimental procedure is presented in Figure 5.

Figure 5. Experimental procedure



3.3. Measuring tools

3.3.1. Pre- and post-test of knowledge

3.3.1.1. Pre- and post-test of factual knowledge

The knowledge test was self-constructed based on the content covered in the integrated curriculum. The test comprises a series of factual knowledge questions about STEM and social service. The pre-test consisted of seven questions testing factual knowledge and one design challenge. For example, in testing STEM factual knowledge, one of the questions was:

> Which of the following is an input device?
> A. Buzzer, B. LED Screen, C. Infrared sensor, and D. Motor.

In testing social service knowledge, one of the questions was:

> What technology products do you know of that can help the underprivileged people in the community (e.g., people who are visually impaired or have poor living conditions)? Please list one product.

To ensure the validity of the test, the STEM part and the social service part of the test were drafted by one experienced STEM teacher and one experienced social service teacher of the project, and then reviewed by two experts in the field (Moss, 1992). After revision, it was further reviewed by two secondary school teachers to ensure readability. To establish internal reliability of the test scores, the test was marked by two scorers following a marking scheme with examples. The first rater trial scored 20 submissions, and then scored all the remaining submissions. The second rater randomly selected 30% of the papers for scoring, and the scores were compared with the first rater. The percent agreement (Campbell et al., 2013) between the two scorers was 92%. The same set of questions was used for the post-test to be consistent in understanding students' changes after completing the curriculum. It ought to be noted that the pre-test was done in the classroom, and the post-test was organized through Zoom due to the outbreak of another wave of disease in Hong Kong. Students were informed that the test results impact their course grades.

3.3.1.2. Pre- and post-test of design competence

In the design challenge, students were given a situation and were asked to propose a solution to the problem. This approach was inspired by Atman (2007), who used the challenge of designing a playground for the neighborhood to compare the design competence of undergraduates and expert designers. In the study, as the learning content was focused on social service and STEM, we evaluated students' design competence in designing a traffic light for the visually impaired group. The description of the design challenge is presented below:

> If you are a product designer and need to design a traffic light for the visually impaired, how would you design this traffic light? Please list: (1) the features of the product; (2) the main functions; (3) the input and output devices that will be used; (4) the reasons behind this design; (5) and introduce the design with a picture.

The marking scheme refers to the scoring method of scientific problem solving proposed by the Organization for Economic Cooperation and Development [OECD] (2019). The OECD (2019) uses a three-level system for evaluating students' scientific problem solving, i.e., full points for appropriate and original, partial points for appropriate only, and no points for all other cases. The advantage of using the system is that this criterion is easy to understand by the scorers with minimum training, and thus is more likely to promote the reliability of the scoring results. The same design challenge was used in the post-test. The marking scheme for design competence is shown in Table 3.

A marking guideline with examples was presented and introduced to the first scorer. After a trial scoring of 20 submissions, the first scorer marked all the remaining submissions. Then, another scorer randomly selected and marked 30% of the submissions. The percent agreement (Campbell et al., 2013) between the two scorers was 90%.

Table 3. The marking scheme for design competence

Dimensions	Corresponding sub-questions	Scores
Defining design goal	Features & Main functions	• 2 points: Correct, reasonable • 1 point: Partially correct, partially reasonable • 0 point: Unreasonable, incorrect
Technical knowledge/skill(s)	(1) Input device	• 2 points: Correct, reasonable • 1 point: Partially correct, partially reasonable • 0 point: Unreasonable, incorrect
	(2) Output device	• 2 points: Correct, reasonable • 1 point: Partially correct, partially reasonable • 0 point: Unreasonable, incorrect
Reasoning	Explanation of the design rationale	• 2 points: Correct, reasonable • 1 point: Partially correct, partially reasonable • 0 point: Unreasonable, incorrect
Visual presentation	Picture of the design	• 2 points: Correct, reasonable • 1 point: Partially correct, partially reasonable • 0 point: Unreasonable, incorrect
Creativity	Overall design	• 2 points: Reasonable and different from the solutions of most students • 1 point: a. Partially reasonable, different from the solutions of most students; or b. Partially reasonable, proposed two or more solutions but similar to other students' solutions • 0 point: Similar to the solutions of most students.

3.3.2. Survey questionnaire

The questionnaire consists of 12 items in 3 dimensions, including empathy, self-efficacy, and interest. The questionnaire employed a 6-point Likert scale ranging from "1- strongly disagree" to "6- strongly agree". In the dimension of empathy, the items were adapted from the instrument of Vossen et al. (2015), which measures people's empathetic mindset and sympathy. One sample item of the empathy dimension is "When people talk about how they feel about community service, I listen attentively." In the dimension of self-efficacy, the items were adapted from the instrument of Chen et al. (2001), which examines people' beliefs in their capabilities. A sample item of the self-efficacy dimension is "I believe I can design a good STEM solution to improve community service." In the dimension of interest, the items were adapted from the instrument of Luo et al. (2019), which evaluates people's interest in different subjects. A sample item of the interest dimension is "I want to learn as much STEM knowledge as possible." To understand the changes of students in emotion and motivation after completing the course, we pre- and post-questionnaire. The newly assembled questionnaire was subjected to expert review (Moss, 1992) by three university professors for face validity. After revision, it was further reviewed by three secondary school teachers to ensure readability.

3.3.3. Student interviews

To gain a deeper understanding of students' perceptions of the transdisciplinary curriculum, we invited 14 students to participate in 4 group interviews with their mother language. Each interview involved 3 to 4 students, lasted for 30-50 minutes. All interviews were audio-recorded and transcribed. The interview questions are: "(1) What is your overall feeling about the curriculum?; (2) Which part of the curriculum do you like best? Why?; (3) Which part of the curriculum do you think needs improvement? Why?; (4) Do you expect to receive any extra support?"

4. Results and discussions

4.1. Pre- and post-test of knowledge

4.1.1. Analysis of factual knowledge

To maintain the consistency of data analysis, only the students who participated in both the pre- and post-tests were included for data analysis. In total, 83 students participated in both the pre-test and post-test. In terms of factual knowledge scores, a paired sample *t*-test was conducted to examine if there was any difference between students' factual knowledge scores before and after the project. The results indicated that there was a significant difference in the factual knowledge scores for pre-test ($M = 8.41$, $SD = 3.45$) and post-test ($M = 9.63$, $SD = 3.51$); $t(82) = -2.64$, $p = .01$. See Table 4.)

Table 4. Pre- and post-test results of factual knowledge and design competence

		Mean (*SD*)	*n*	*t*	*p*-value
Factual knowledge	Pre-test	8.14 (3.45)	83	-2.64	.01
	Post-test	9.63 (3.51)			
Design competence	Pre-test	5.04 (1.94)	44	-3.10	< .001
	Post-test	6.33 (2.71)			

4.1.2. Analysis of design competence

Similarly, only students who submitted both the pre- and post-designs were included for data analysis. In total, 45 students submitted both the pre- and post-designs. A paired sample *t*-test was conducted to examine if there were any differences in students' design thinking scores. The results indicated that there was a significant difference in the design thinking scores for pre-test ($M = 5.04$, $SD = 1.94$) and post-test ($M = 6.33$, $SD= 2.71$); t $(44) = -3.10$, $p < .001$ (see Table 4). As mentioned in the research methods part, the post-test was organized via Zoom because of the outbreak of another wave of disease. Some students may not have uploaded their design pictures due to the inconvenience of doing so, and some students may have skipped this part due to the complexity of the task. This is a limitation of the study.

The test results demonstrated student improvement in both factual knowledge and design competence. The results are more positive than several preceding studies in the COVID-19 context, which reported a loss of learning amongst their findings (e.g., Engzell et al., 2021). There are two possible reasons for the improved outcomes. One is that the EDIPT model gave students ample opportunities for inquiry. It enabled them to integrate all the lessons they learned with solving social problems. Thus, it triggered students' interest in STEM and design. In this process, students build up their knowledge step by step. The results are consistent with the previous finding that connecting learning with real-world problems led to increased interest and achievement (Linnenbrink-Garcia et al., 2016). A second possibility is that it was facilitated by adequate and timely support. For instance, in the STEM course, videos for the hands-on sessions were made available, so if students could not keep up with teachers' pace, they could follow the videos instead. In addition, e-handouts were provided to allow students to choose their preferred medium to follow, either the video or the e-handout, which catered to learner differences. Consideration of individual differences and needs has always been a paramount issue for STEM teachers. In the social service course, the method of answering the guiding questions on the worksheet while watching videos also consolidated the content they learned (Azlan et al., 2020).

4.2. Pre- and post-test of emotion and motivation

4.2.1. Analysis of learner empathy

To ensure the consistency of the comparison results, we analyzed the questionnaires of students who completed both the pre- and post-questionnaires. A total of 97 students completed both the pre-questionnaire and the post-questionnaire. The Cronbach's alpha result of the empathy dimension was .85. The paired-sample *t*-test result indicated that there was a significant difference in the learner empathy for pre-test ($M =4.45$, $SD = 0.89$) and post-test ($M =4.80$, $SD = 0.89$); $t(96) = -3.69$, $p < .001$, which demonstrated that students had a significant increase in empathy after completing the project.

4.2.2. Analysis of self-efficacy

The Cronbach's alpha result of the self-efficacy dimension was .91. The paired-sample *t*-test result indicated that there was a significant difference in self-efficacy for pre-test ($M = 3.97$, $SD = 1.07$) and post-test ($M = 4.59$, $SD = 0.98$); $t(96) = -5.45$, $p < .001$, which demonstrated that students had significant increase in self-efficacy after completing the curriculum.

4.2.3. Analysis of interest

The Cronbach's alpha result of the interest dimension was 0.83. The paired-sample *t*-test result indicated that there was a significant difference in self-efficacy for pre-test ($M = 4.20$, $SD = 0.98$) and post-test ($M = 4.62$, $SD = 1.09$); $t(96) = -4.02$, $p < .001$, which demonstrated that students had a significant increase in self-efficacy after completing the project.

The analysis results revealed substantial improvements in students' empathy, self-efficacy, and interest. In the social service course, the first step in product design is to understand the difficulties of potential users. Hence, the improvement of empathy is in line with the original purpose of the course, which is to develop students' empathetic attitudes. The result is consistent with the evidence in the existing literature making connections to social issues strengthens students' empathy (Carlson & Dobson, 2020). In terms of self-efficacy, as mentioned earlier, adequate and timely support played an essential role in enhancing students' self-confidence. Moreover, the smooth advancement of their design under the EDIPT model's guidance also contributed to the enhanced confidence. The result is consistent with Liedtka's (2018) observation, that is, the clear structure of the EDIPT model provided people confidence in innovative design. In terms of interest, the searching for answers to the design problems stimulated self-generated questions and promoted more profound interest (Harackiewicz et al., 2016). There are several advantages in implementing a cross-curricular STEM curriculum design. On the one hand, when students can apply their STEM knowledge to solve real-world social problems, their interest in STEM technical knowledge would be enhanced (Quigley et al., 2019) compared to a STEM-only course. On the other hand, if we have students solve social problems without teaching them sufficiently complex technical knowledge, their solutions could be superficial and less specified.

4.3. Student perception of the curriculum

Interview with the student participants indicated that the transdisciplinary curriculum influenced their empathy, transdisciplinary knowledge, creativity, and willingness to learn. They also expressed the need for more in-class interaction. An interesting phenomenon is that even though the group collaboration mainly happened after class, students expressed that they enjoyed collaborating with teammates. Pseudo names are used in the report to protect the participants' identities.

In response to the question "What is your overall feeling about the curriculum?" students commented:

> Carrie stated that, "*It helped us understand the needs of the people in the community. For example, previously, we knew that people with visual impairment needed help, but we did not know their specific needs. We now have a better understanding of their needs after taking this course*." [Empathy; transdisciplinary knowledge]

> Jerry commented that, "*It stimulated us to observe more details in our daily life. I pay more attention to people in the street to see if anyone needs help. If anyone needs help, I would go ahead and help them out. For example, if something falls out of one's grocery bag, I would pick it up for him or her*." [Empathy]

In response to the question "Which part of the curriculum do you like best? Why?" students commented:

> Henry responded that, "*I like the teamwork part the most, especially the ideation of the product. Because we generated the product idea on our own, and we had lots of discussions on the feasibility and usefulness of the product. We also communicated a lot on how to implement it. The process brings us lots of fun.*" [Collaboration; ideation; fun]

> Jack expressed that, "*Through this learning, we have gained a deeper understanding of STEM. In the meantime, the teamwork brought us together. We came up with our design ideas together, so it made us feel the activity was interesting and meaningful*." [Transdisciplinary knowledge; ideation, collaboration]

Kevin expressed that, "*By doing this project, my creativity improved. In order to complete this project, we came up with many different ideas*." [Creativity]

Regarding the questions "Which part of the curriculum do you think needs improvement? Why?" and "Do you expect to receive any extra support?", most students expressed that they were satisfied with the support and abundant learning resources available at the school, including learning videos and e-handouts. One student made the following suggestions:

Martin suggested, "*In addition to writing proposal, verbal expression is also important. I hope I can have more opportunities to share my ideas verbally, because after speaking out, I will get feedback from peers. Even if it is a critique, you will know which idea is reasonable and which is wrong. Thus, it is a good learning opportunity for us. In addition, expressing our opinions is a good chance to practice our oral presentation skills*." [In-class interaction; verbal expression]

Students also made another suggestion. They expressed that they hoped there could be chances to learn more about STEM and social services. They understood it might be hard to arrange it in class, but perceived it helpful if some self-directed learning resources could be provided in future courses. They expressed that it would be acceptable if teacher guidance is provided occasionally rather than all the time.

In general, students' interview results were consistent with the survey results. The students developed a sense of empathy and were more willing to help others. Students also perceived gaining a more concrete understanding of users' needs, which could be an indicator of enhanced self-efficacy. The students reported continuous intentions to help others and learn more after the courses ended. This result showed that they developed an interest in learning the topic. These findings are quite satisfactory in comparison to several other studies that reported lower student interest in learning in the COVID-19 setting due to a lack of classroom interaction (Ewing & Cooper, 2021).

5. Conclusion and recommendations

Despite the myriad challenges and obstacles facing educators as a direct consequence of the COVID-19 pandemic, there are still opportunities to improve student knowledge by deploying efficient and practical approaches. This study adopted the EDIPT model as the theoretical framework for designing the transdisciplinary social-scientific curriculum. Responding to the constraints caused by the epidemic, multi-model video-facilitated learning approaches were used to organize the classroom activities. While video-based flipped learning is well established to support secondary school subject-based learning (e.g., Jong, 2017; Jong et al., 2019; Lo & Hew, 2021), this study demonstrates that it can also facilitate transdisciplinary STEM learning using the proposed approach. Overall, the video-facilitated transdisciplinary STEM curriculum led to positive changes in students' factual knowledge, design competence, empathy, self-efficacy, and interest.

The curriculum design and the strategic adaptations in the COVID-19 context have meaningful implications for a smooth implementation of STEM teaching during post-pandemic recovery. Firstly, it addressed the gap of having a distinct lack of research in the literature on the crossover of social service and STEM disciplines. The integration of social service, writing, and STEM to develop transdisciplinary skills in secondary school students is a novelty of our work. Due to the complexities of conceptualization, administration, and implementation, interdisciplinary integration is not yet a well-learned field (Cheng & So, 2020). Few studies have explored the pedagogical integration of three or more disciplines. Besides, previous studies have rarely emphasized the importance of designing products for people in need in the community, such as the visually impaired. As this study shows, transdisciplinary STEM teaching and learning can be a way out to empower learners with design competence and transdisciplinary knowledge. Secondly, it also provided evidence on the effectiveness of video-based innovation in supporting learning. The video-based innovation (1) ensured that students were able to successfully carry out STEM learning with minimal disruption when regular STEM in-class time was heavily curtailed; (2) facilitated a connection between students and the real-world context, which enabled them to understand the users' needs better; (3) catered to learner diversity by allowing students to pause or replay hands-on sessions according to their own progress, which consequently increased their confidence in completing more technical challenges.

The COVID-19 is now in its fourth wave, and the fluctuating situation compels us to be flexible in dealing with the new norm. Some of the lessons learned in the study can inform STEM course design irrespective of an epidemic or normal context. Drawing on experience accrued from the study, we have the following recommendations for future STEM curriculum design:

- Put introductory information and conceptual knowledge in pre-class videos to save class time for more challenging issues.
- Use in-class videos in hands-on sections to offset difficulty levels for students, and accompany the videos with e-handouts to allow students to choose their preferred medium.
- Build up a knowledge foundation for students before engaging them in designing solutions to real-life problems.
- Provide a gateway to understanding users' needs through field visits or video-based field visits.
- Arrange on-site supporters for students in the hands-on sessions to provide timely feedback.
- Consider a new collaboration model, i.e., one teacher responsible for live broadcast and the others responsible for on-site support, to alleviate the increased workload in adaption to the emergent situation.

6. Limitation and future research

One of the limitations of this study is that the classroom design should have included more student interactions. Due to the demands of social distancing and short class time, we limited class interactions. When students collaborated on group assignments, they discussed them after class through instant communication tools, e.g., WhatsApp® or Zoom®, without any teacher or mentor involvement. During the limited in-class discussion time, the teachers explained the group work requirements and scaffolded their discussion with prepared worksheets, but did not model any answers to give students more control over their projects and encourage creative thinking (van Leeuwen & Janssen, 2019). If time permits, more student-to-student interactive activities such as peer sharing could be introduced inside the classroom to make the course more engaging and allow students to learn more through peer interaction. Additionally, it would be interesting to explore if other strategies can be implemented to enhance in-class engagement. Video-based field visits have proven to offer specific advantages. For example, they can reduce the financial cost and staffing needed to organize large events (Chang et al., 2020; Jong et al., 2020). It has more flexibility in terms of time, as teachers can show it in class at any time. If conditions permit, it would be more beneficial to have students visit social service organizations in person, which is even more impactful than the video-based field visit (Friess, 2016). Due to the unique context, this study conducted a single group pre- and post-test experiment. In the future, a comparison group can be included. In general, it is an exciting exploration to connect social service with STEM education. Further research in this direction would be imperative.

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Appendix I. The video-facilitated strategies in the COVID-19 context

	Challenges	Video-facilitated strategies	Other administrative support
STEM	• Shortened class time; not all knowledge can be taught in class. • No group work in the classroom, which makes learning more challenging for individual students. • Individual differences in students' understanding and operating proficiency.	• Pre-class: Provide less than 3-minute short videos to introduce the introductory concepts. • In-class: Pre-recorded all hands-on sections. Students can follow the video in the hand-on sections. The videos are accompanied by e-handouts.	• To alleviate the workload faced by teachers in adapting to the adjusted instructional content and approach, the STEM teaching team made adjustments to their collaboration approach. One teacher gave lectures through live broadcast, while one teacher and one student mentor provided on-site support in every classroom. Students could seek help directly from the on-site mentor if they had technical problems during the hands-on session.
Social service	• There is no field visit, so students' understanding of the users' needs may be vague. • The direct instruction format may not engage students. • The class time is shortened, and it is impossible to cover	• In-class: Video-based field visit. The project team visited the social service organizations prior to the course, and interviewed the potential users and the staff working in the social service organizations. Students could watch a video to learn about the potential users' difficulties in daily lives and identify	• Similarly, for the social service course, one teacher gave lectures to four classes simultaneously via live broadcast, and one teacher in each classroom guided students to complete worksheets and discussions.

	all the contents in the class.	their needs. • While watching the video, students would answer the guiding questions on the worksheet to record the users' essential needs. • Post-class: Students could watch the extracurricular extension videos on their own. Students could watch the extracurricular extension videos on their own. The videos introduced some new high-tech products that can help people in need.	
Proposal writing	• In the format of direct instruction, students may have a vague understanding of the product development background. Students may not have a clear understanding of how to introduce a product in the form of a proposal.	• In-class: Showed selected exemplars of technological products and instructed students to complete the proposal worksheet for a sample product.	• Lessons were taught by the language teacher of each class.