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Characteristics of an effective secondary school design thinking curriculum

Abstract
This study examines the effectiveness of course materials, design methods and teaching strategies in a design thinking-based curriculum. As part of a multiple case study, we developed, ran and studied an interaction design course for Canadian students in grade 9 and grade 10 (14–15 years old). We gathered qualitative data in the forms of interviews of students and teachers at the end of each class and at the end of the course, and we observed their activities and performance throughout the course. We also evaluated the curriculum by tracking the changes we made and justifying the intentions behind these curriculum modifications in the context of the research. From this research, three main curriculum characteristics were found to be essential for a design thinking course to be effective and engaging: experiential activities, real-world applications and characterised consequences. We recommend that design educators consider these characteristics.

Keywords: Design thinking, creative problem solving, interaction design, curriculum development

Introduction

Design thinking aims to foster innovation by elevating the creative thinking abilities of the participants. It usually involves a problem-solving approach to tackle complex problems, which can be best achieved through collaborative and human-centred activities. In post-secondary education, design-thinking techniques and practices have been implemented into different curricula as skills that need to be learned in the 21st century (Akalin and Sezal 2009; Wormald 2011; DeVere et al. 2010; Lugmayr 2011; Klein and Phillips 2011). Moreover, these approaches to design-based learning have been implemented into secondary level education to support students' learning through a variety of projects, including the complex structural and functional components of a respiratory system (Hmelo et al. 2000), geography systems and elements (Carroll et al. 2010) and the concepts applied to different fields of study (Dukes and Koch 2012). However, the lack of sufficient knowledge about and studies investigating the implementation of a design thinking-based pedagogy in the context of secondary education is the reason for this study.

According to the d.school's (The Hasso Plattner Institute of Design, known informally as the d-school, is a well-known leading school in design thinking and innovation based at Stanford University.) definition, the design-thinking process uses a human-centred approach to create innovative solution(s) to a problem by following a five-step design process: empathize, define, ideate, prototype and test. The entire process focuses on developing a d-studio 'mindset', which enables individuals with no design experience (non-designers) to think like designers. In practicing a design-thinking mindset, individuals should show, not tell, focus on human values, craft clarity, embrace experimentation, be mindful of their process and collaborate with other innovators with varied backgrounds to build solutions (Bootcamp Bootleg D.School 2011). Being involved in a design-thinking process can provide an individual with an opportunity to gain specific skills and knowledge, such as idea generation and prototyping, in order to become a creative thinker. Several studies have introduced strategies that foster creative thinking and creative performances of students in design-based pedagogies.

Kowaltowski et al. (2010) studied methods that design instructors used to stimulate the creativity of students. They provided design educators with a practical guideline for understanding how teachers recognise functional creativity in students' products, and how their teaching promotes student creativity. The creativity criteria that need to be recognised by design education instructors include relevance, effectiveness, novelty, elegance and genesis. These criteria can be best fulfilled through pedagogies that: 1) provide students with appropriate practice in solving a design problem, 2) provide systematic training based on real examples, 3) promote practices to improve students' knowledge and skills and 4) include activities involving a range of broad-to-focused tasks. Moreover, they emphasised such things as how the open-ended nature of design problems is an important factor in creativity. Additionally, Benson and Lunt (2011) identified ownership, motivation, space, time, interaction and collaborations as key elements to encourage the creative performance of students. Furthermore, Howard-Jones (2002) suggested considering a dual-state model of creative cognition that involves primary thinking (a generative and exploratory process) and secondary thinking (a logical, critical and analytical process).

While the importance of design thinking in stimulating creativity of students has been well explored in the literature, there is no study on effective design-thinking curriculum characteristics for K-12 (a short form for the totality of primary and secondary education, kindergarten and grades 1 through 12). We define 'effective' as successful and preferable curriculum materials that are easily replicable in other similar contexts. In this study, we investigated how to best design and implement interaction design thinking in the context of secondary education. We specifically examined the effectiveness of the curriculum materials through close investigation of the students' learning experiences inside and outside of the classroom. We undertook a multiple-case approach that examined the implementation of a nine-week interaction design thinking course in two secondary schools: Mulgrave and Stratford Hall secondary schools, located in Vancouver, British Columbia (Canada).

Research methodology

The study sought to answer the following research question: Which course materials or activities should be utilised in teaching an effective interaction design thinking course for K-12 education? To address this question, we carefully tracked techniques and materials that we included and excluded from the curriculum. We also reflected on the reasons for making those decisions (Table 1). We interviewed the instructor who taught the course and the school teachers (who were present during each class to provide additional help when needed) after each class and at the end of the course to evaluate the perceived success or failure of the course materials. On average, each interview took 15–20 minutes per individual to complete. We specifically asked the school teachers and the course instructor:

- If they have any comments about the techniques and materials used in the course.
- What worked and what did not work in the course.
- What was the most challenging part of teaching the design thinking course (course instructor).
- What could be enhanced in future design thinking courses; and
- If they had any general comments about the course.

In addition to the interviews, we observed the students' performances throughout the course to determine which course activities did or did not work for them.

We taught the course and conducted the research at two secondary schools (Mulgrave and Stratford Hall). To collect qualitative data, we interviewed 39 students, the course instructor, and four school teachers who were present during all of the classes. Three different types of data collection techniques were applied: 1) participant observation, including observing, recording, analysing and interpreting the students' behaviours and attitudes during the course,

2) semi-structured interviews with school teachers about the success or failure of the course material and 3) focus groups with students about the success or failure of the course material. We used member checking and triangulation of data from these three different sources to propose reliable findings.

The grounded theory technique of coding was used to analyse the textual data. As part of grounded theory, we utilised line-by-line coding, which required highlighting important sentences that revealed the participants' condition, context, actions/interactions (including strategies) and consequences. Furthermore, the initial codes for observation notes were assigned a letter that helped in dividing the codes based on the different research questions. After this step, the data were classified through axial coding and memo writing (Charmaz, 2006).

Interaction design thinking curriculum

Since our main research goal was to study the effectiveness of curriculum materials not to create new ones, we adapted an existing course (Project: Interaction curriculum by Dukes and Koch 2012) that had previously been implemented and tested. The curriculum included a 10-week after-school programme that taught high school students in grade 9 how to use design thinking to solve real-world problems in their communities. The discussions and activities were built around interaction design concepts and techniques; however, we made several changes to our curriculum that were not included in the existing Project: Interaction (Dukes and Koch 2012): 1) our study was larger in terms of its scale and the number of students, 2) the course in our study was conducted as part of existing design and computer technology courses taught during regular school hours (the course was not a voluntary after-school activity), 3) our study focused on evaluating the curriculum and the learning benefits for students and 4) several extensive changes were made to the original curriculum in order to adapt it to the new context, timeline and research-specific activities to gather qualitative data. The final curriculum included nine, one-hour sessions, which were scheduled as part of two secondary level courses: Design (at Mulgrave) and Computer Technology (at Stratford Hall).

Curriculum modifications and rationales

We made several changes to the Project: Interaction course syllabus. First, since the curriculum's lesson plan was introduced to us in the form of blog postings, we had to reorganise the content into a formal course plan. We adapted the curricula to match the learning outcomes of each session with in-class activities. In the original curriculum, the activities did not quite match the learning outcome in each session. Moreover, the timeline was an issue for us because we had to include several new research-specific activities in the curriculum. Because the timeline was a one-hour course per week for nine weeks, we had to modify the length of some of the activities and set a new timeline. We strictly followed the design thinking steps, so some of the activities were shifted to the earlier or later sessions. For example, the prototyping activity was moved to an earlier class. Finally, specific activities, such as sketchbook homework, were revised so they would be better aligned with other activities in each session, thus creating a more meaningful learning experience for students. The information presented in Table 1 illustrates the major curricular activities, the changes made and the rationales behind each alteration.

Table 1. The curriculum changes and their rationales.

	Course material	Modifications	Rationale
Week 1	*Ice breaker*	An ice-breaker was added to the first part of the session to get to know the students through the questions: What is your name? and What do you think design is?	1) Get to know students. 2) Review the student-made definition of design and clarify misconceptions of design and interaction design.
	Pull apart an object	Provide students with a variety of physical objects and have them discuss in a group: "Who is it for? What is it for? Why does it exist? Are there other types of the same thing?" In the original curriculum, the students were given images of objects to students to write about.	1) Encourage discussion and group work from the beginning of the course. 2) Provide students with a physical and interactive object to explore.
	Make an 'interactive product'	The making prototype activity was changed to making a concept to discuss what constitutes an interactive product. Students also were asked to 'tell a story' about the product, covering its purpose and use.	1) The making a prototype activity was out of place considering the design-thinking process. 2) Ensure that the students discuss what constitutes an interactive product.
	Sketchbook homework (weeks 1–6)	Give the students a specific question to sketch out their ideas. For the second class, students were asked to fill out at least two pages with sketches visually indicative of what skills or interests they think might make them successful designers.	1) To encourage students to use their sketchbooks more purposefully. 2) To align the sketchbook assignment with in-class activities in order to connect them. 3) Not leave the activity completely open-ended to give students some direction.
	Group formation	Form groups earlier. Creating a logo could be done later at home.	Due to the course time limitation, some activities were completed at home.
Week 2	*Sketchbook recap (weeks 2–6)*	Students sat around a large table to see one another's work, and the course instructor led a discussion to draw out points about good ideation.	To discuss and share the sketchbook activity in a larger group. Help students see one another's successes and failures.
	Research-specific activity	Spend 25 minutes on problem solving, human-centred and collaboration questions.	To collect data from students indirectly.
	Brainstorming challenge	Change the Gamestorming activity in the original curriculum to a brainstorming activity.	1) Provide a more practical problem-solving technique so students can use the technique in different contexts. 2) Time limitation.
Week 3	*Describing an Environment*	Changed the storytelling to storyboarding technique: Students came up with a description of a common place in the school and their experiences there (instead of a place that they visit every day).	1) To merge sketching and storytelling. 2) To use a familiar context: A shared environment among all students.
	Understanding an Environment	Observation: In their teams, the entire class went and experienced a space in silence. Afterwards, everyone shared their findings with the larger group.	1) To assess a space before and after visiting, and to understand the purposes behind the observation technique. 2) To draw out the differences in students' experiences and perceptions of the space.
	What is User-Centred Design?	Using points the students uncovered, discuss how user-centred design becomes important/relevant.	1) To recap the students' understanding of users and shaping products for them 2) To help the students understand how we create products that fulfil a need.

	Course material	Modifications	Rationale
Week 4	*What is ubiquitous computing?*	Using the scenario of making pancakes in a different era to define the benefit and limitations of a mobile phone interface. Recapping what defines 'ubiquitous computing'.	Define ubiquitous computing and its implications for designers.
	Bodystorming	In their groups, students practiced some bodystorming (acting out scenarios; using storytelling techniques). Not many changes happened in relation to the original curriculum, but we clarified the purpose of the activity for students.	Due to the playful nature of the activity, bodystorming is appropriate for the students in this age group.
Week 5	*Practicing Designer*	No changes were made to the original curriculum.	1) Gain access to practicing designers. 2) Use storytelling techniques to explain design concepts.
	Improving Services	With the guidance of a guest designer, students stepped through the design process, improved an existing service and presented their improvement to the larger group.	1) Interviewing in the original curriculum was out of place. 2) This activity was connected to their sketchbook homework that was due in week 5.
Week 6	*Recap the Process*	Revisit the process and ideas we covered, including the concept of user-centred design and the design-thinking process using visual representations.	1) Recap the design techniques and processes to enable students to employ appropriate techniques for their final project. 2) Show them a holistic view of the design process, and how the design stages are connected.
	Interviewing for Ideas	In their groups, students asked one another questions about the last time they were frustrated, and they wrote down their responses. Based on the responses, the students then had a pool of options to they could use to work on for their final project.	To find realistic problems based on people's experiences.
	Project Work Time	Students should aim to have a topic, an idea of what they need to research and a plan for how they will work on their project.	Students determined the topics for their final projects based on the interview activity.
Weeks 7, 8	*Project Work Time*	No major changes were made to the original curriculum. Students had the entire session to work on their project. By the end of the session, they had enough experience to complete their poster.	Having sufficient time to work on the description of the problem, the process and the solution.
	Research-specific activity	Interview the students about the course.	For research purposes.
Week 9	*Final presentation*	Have all the teams present their work; provide a brief critique bout their work.	1) Enable students to ask questions and reflect on one another's work. 2) Encourage critical thinking.
	Research-specific activity	Spend 25 minutes on problem solving, human-centred and collaboration questions.	For research purposes.

Curriculum characteristics

The curriculum uses an inquiry-based, human-centric approach that follows the different stages of design thinking. An inquiry-based curriculum can be oriented towards solving problems in different subject areas, and this curriculum was product- and service-design oriented, which enabled the students to explore the potential problems that people face in their everyday lives. The overall goal of having different design-oriented subject areas was to teach the students that design-thinking approaches and strategies could be used to solve a variety of problems. In this course, the students' final projects provided solutions for a range of problems, including microwave interference of Wi-Fi at home, messy rooms, breakable trash bins, texting and driving and traffic problems. The main characteristics and strategies of the curriculum are presented below:

- The course materials were connected and relevant to real-world scenarios, so the activities and assignments were more meaningful for students to complete (Aflatoony et al. 2015).
- Students learned about the entire design-thinking process, not just design techniques or activities. We also recapped the design-thinking process in the sixth session to illustrate how the design techniques and steps are relevant to design thinking as a whole.
- The course materials and activities followed the same order as the design thinking stages.
- The course materials and concepts were human-centric and encouraged 'design for people'.
- All the activities were designed to be completed in teams. Hence, we developed the 'research activities' to be completed collaboratively, in a group.
- When searching for a problem to be solved, we purposely introduced students to the interview and observation techniques to enable them to find realistic problems. Consequently, the students did not need to be introduced to any pre-defined problems.
- The teaching materials and discussions were all developed around interaction design concepts and definitions. We also provided students with physical products (digital and non-digital) in the first session to encourage discussion around the topic of interaction design.
- We encouraged the students' critical thinking through in-class discussions, asking questions around the topic that week or having them reflect on one another's projects.
- Combinations of verbal and visual instructions were incorporated into the teaching materials (show and tell).

Effective course materials

This section provides an overview of the findings that answered the research question: *Which course materials or activities should be utilised in teaching an effective interaction design thinking course for K-12 (grade 9 and grade 10) education?* The findings are from the interview sessions with students and teachers, as well as observations of how the students performed in every activity during the course. First, we will provide an overview of the common findings for each activity, and then we will summarise the findings according to three main categories: experiential activities, real-world applications and characterised consequences.

Sketchbook activity

Several students showed an interest in doing the sketchbook activity. As one student stated: "I enjoyed our little note pads, little small homework sketches we had to do. I thought that worked really well". However, the students suggested completing the sketchbook activities in-class rather than at home. The students provided comments about having this sketching be part of their in-class activity. One student noted: "I think sketching should be [done] during the class

you know, so you have some ideas right there and you build them at the time… the sketch can be done later though it's disconnected with what you are doing". Another student explained that she found the questions to be too broad: "Sometimes the questions for sketches were a little bit broad, so we actually had to think about it; it was a good thing, but hard to finish". According to the course instructor, the sketching did not work quite well for the Stratford Hall students: "Things like sketching didn't work out well for this group. They just forgot about it; they didn't bring it into the class. Having them sketching in the class, working on sketching and developing that will be taking them a little bit further. Especially with this group, [that] would have been good". To confirm this, one student stated: "It was really cool having to draw the ideas into the notebook. I just didn't think I'd have to bring it because I really have bad organisation". Another student explained that: "The sketch can be done later, though it's disconnected with what you are doing". According to his statement, although he had no issue completing the sketch at home and bringing it back to school, he saw the disconnection between the activity and the course materials.

The course instructor also explained that introducing the assignment clearly and having more formal discussions around the activity could be beneficial: "There were varying levels of understanding what the sketching was, and it would be nice to have a bit more formal discussion early about what sketching was". He further explained: "I'd also be curious about trying to integrate more about sketching, and just getting sketching done as a practice […] So, having them do a nice sketching activity where they get the sense of why we sketch and this is sort of how we go about sketching if we are not a good drawer, or so on".

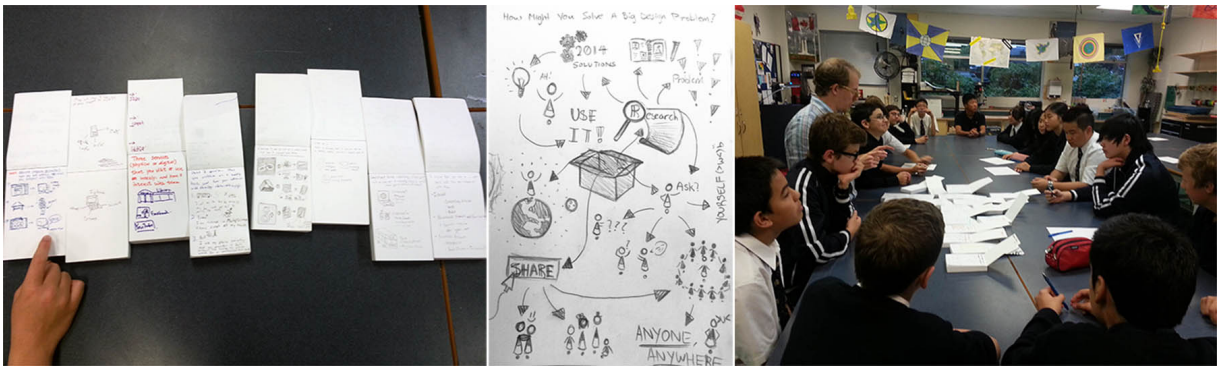

Figure 1. Recapping sketches at the beginning of each session.

In summary, the students found the sketchbook questions to be too broad, they sometimes forgot to bring their sketchbooks and they did not quite understand the main purpose for doing the sketchbook activity. Leaving assignments to be completed later at home can be problematic due to the lack of organisational skills of students at this age. One student suggested the following solution to avoid the lost sketches: "Maybe you keep the sketches for us". Moreover, having clearer and more focused questions, completing the activity during the class, as much as possible, and providing more context before starting an activity would be critical when teaching design thinking grade 9 and grade 10 students.

Observation Activity

The observation activity was effective in that the students paid attention to the details when observing the space, and they provided examples of what they had not noticed before. One student stated: "I actually liked the little field trip to the lounge because I got to see more things and it was like being in a trip". Another student explained the experience as follows: "You guys taught us to look at things we may not have noticed before; like we went to the lounge and

marked down things we never notice, but when we take a close look at them we see that they are always there".

In addition to the students, the course instructor acknowledged the success of the activity, and explained the activity as follows: "I remember the observation task actually worked out surprisingly well for me. I was kind of concerned if they were just chatty, but they spent a serious amount of time looking at the space and they actually came up with good results". A school teacher stated: "I think the observation task worked really well. I remember them actually getting really super engaged in that one, and actually doing a really good job with that one, which was really surprising to me given their difficulty focusing otherwise. So, we take them out and we walk them down, and was like, okay find the stuff that you don't really pay attention to, and they actually did". The following images (Figure 2) show the students observing in their school.

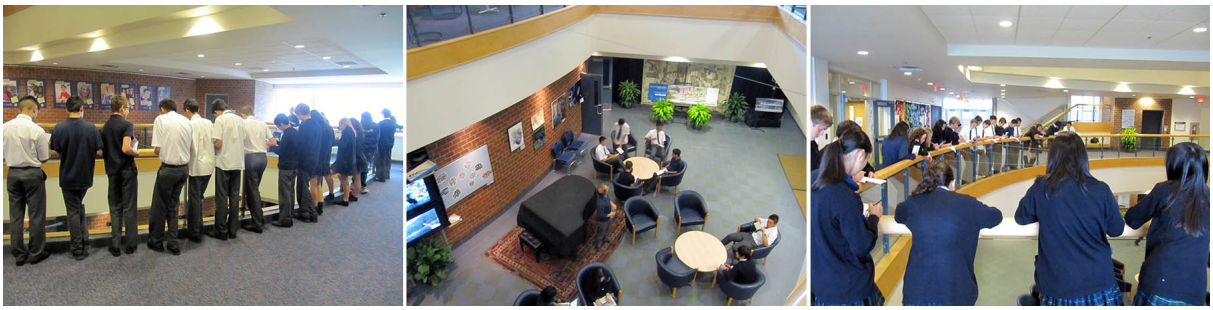

Figure 2. Students took part in the observation activity and later shared their findings with a larger group.

Visit from a Practicing Designer

This activity was effective for increasing the students' understanding of the design process and the steps that a designer follows. It also enabled them to see how the course activities could be applied to their lives. The guest speakers talked about their experiences and introduced several interaction design projects that they had completed before (Figure 3). Students from both schools described their experience as being positive: "You can see how they use it in a real-life situation". "I think that having the guest speaker was pretty cool because it kind of shows that you know what we are learning here can actually be put into like a job, and I thought that was really cool". "Once the guest came in, it was good to see the products that she actually designed herself to like make a connection between what you can actually do when you are looking at the person doing that". "I really like that she shared how it was like to be a designer".

In summary, this category explains the importance of connecting the students' experience to real-world scenarios. Students are typically curious, and they constantly seek answers to their questions. Connecting course content to real-life situations can answer many of their questions by providing more logical and tangible solutions. Overall, creating relevant and connected course activities inside and outside the classroom made the learning process and its content more meaningful for the students.

The interview activity

The interview activity helped students identify real-world problems based on their everyday experiences. We asked the students to participate in an interview activity to identify the problems that they may have encountered in their lives; we also asked them to take notes on three specific things: 1) try to pick a situation and a problem, 2) determine the actual cause of the problem and 3) was the problem resolved?

In the interview activity, many personal problems emerged, such as "I get frustrated with my mom!" or "I never get frustrated! So, I have no answer for the questions; what should

I do now?" We had to suggest they think about community/society issues, not necessarily interpersonal problems. The course instructor explained his idea about the interview activity as follows: "Interviewing felt a little out of place. I think mostly because the way we ended up using it; it didn't quite make sense. I think otherwise, material wise or technique wise, [it] was okay". Overall, while the interview activity introduced students to a useful research technique in the empathise stage of the design-thinking process, more clarification about and adjusting of the interview questions could be beneficial.

Figure 3. The guest speakers described their design experiences in the industry as product designers.

Bodystorming activity

According to our observation, bodystorming is an appropriate activity for this age group. Students were given different problem-based scenarios to perform. They were excited, and they engaged deeply in the activity. They acted out their scenarios well (Figure 4). The activity "seems pretty simple!" as one student explained to us. Students came up with appropriate solutions for each of the problem-based scenarios we assigned to them. However, this activity required careful supervision of the students. While rehearsing their actions, and due to the nature of the activity, the students got excited and started to move around the classroom. They used items they found in the room and, sometimes, played in a way that roused safety concerns. The students also asked us if they could use the space outside the classroom, so having a bigger space would be beneficial for students when rehearsing and playing. The Mulgrave school teacher confirmed the success of the activity stating that: "It works well, and I am thinking of how to use it in future courses". While the majority of the students enjoyed this activity, one student found it challenging: "The time travel thinking, different times with different scenarios it was kind of difficult to think about right away". In summary, this activity engaged disengaged students through playful and exploratory processes, and it enabled them to learn and present their ideas in a different format.

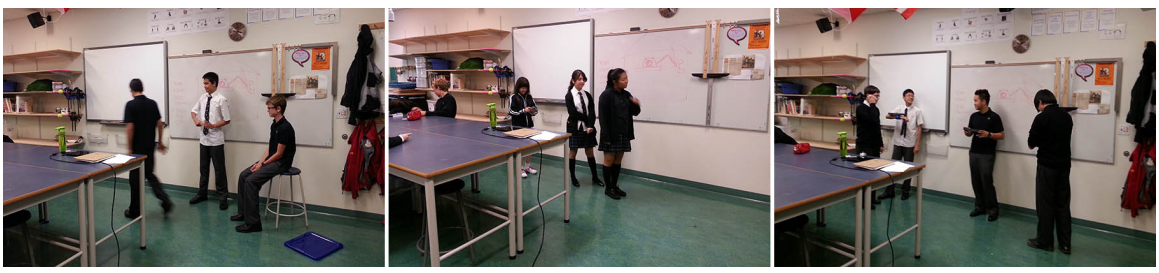

Figure 4. Student role-playing in Bodystorming activity.

The Field Trip

The field trip to the School of Interactive Arts and Technology (SIAT) at Simon Fraser University was effective, according to Stratford Hall teacher feedback. SIAT is an interdisciplinary research-focused school where technologists, artists, designers and theorists collaborate on innovative research and study the human experience of technology. Stratford Hall students had the opportunity to talk to undergraduate students at SIAT. They visited several places, such as the library, fabrication lab, sound and studios, and they were involved in a problem-solving workshop held by SIAT staff and a faculty member (Figure 5). The Mulgrave students were unable to attend the field trip because Simon Fraser University was too far from their school; thus, the findings of this section are limited to the Stratford Hall visit. In regards to the benefit of the field trip for students, one school teacher mentioned: "Two of them were highly affected, especially for those who wanna do more hands-on stuff. The trip was really good because it opened their eyes to the possibilities of other educational opportunities and careers, which is good". Another teacher stated: "I think going to SIAT was really excellent; [a] couple of students asked me about admission requirements and everything, so a couple of them changed their mind about possible career paths so that was very important".

Figure 5. Students visited SIAT and participated in a problem-solving workshop.

Reflections

Reflections and discussions were encouraged throughout the course, which enabled the students to benefit from the variety of ideas. The reflection and discussion activities were encouraged during the lectures and presentations and, during the course the instructor encouraged discussion and active learning by asking questions frequently. Moreover, the students had the opportunity to provide feedback on one another's work during the presentation time. Thus, they learned how to provide constructive feedback and how to ask reasonable questions when discussing a proposed solution. While we found that reflection was beneficial for strengthening the students' critical thinking skills, leaving them to discuss one another's ideas required careful supervision and interruption from the teachers. In the final session, one of the school teachers asked the students to behave more professionally: "We do appreciate that you are passionate…however, this is a respectful place for sharing ideas so if you have question or comments keep them in respectful tone and not in an argumentative one because it really doesn't help to argue". The students sometimes questioned a design solution presented by other students to demonstrate their intellectual superiority. As the course instructor noted: "Student x asked questions to demonstrate intellectual superiority; other groups felt threatened by them. Pulling out problems that obviously have no answer due to the limited time for completing the project or asking questions to pull apart the proposed solution".

Characteristics of Successful Course Materials

This section provides a summary of the qualities and characteristics of the design-thinking techniques and activities that are considered suitable, appropriate or successful according to feedback from the students and teachers. Based on the findings previously described in this paper, the preferred techniques included the following characteristics: *experiential activities, real-world applications* and *characterised consequences.* In other words, a design thinking curriculum that is targeted at secondary education requires using these qualities in order to engage students in all activities.

Table 2 summarises the successful curriculum characteristics, followed by a short description for each and examples of successful activities.

Table 2. Characteristics of successful course materials.

Successful course material's characteristics	Description	Examples of applications
Experiential activities	This category explains the importance of having exploratory and playful activities in a design thinking curriculum.	Observation activity, bodystorming activity, field trip
Real-world applications	This category explains the importance of connecting the students' learning experiences to real-world scenarios.	Field trip, guest speaker, observation activity
Characterised consequences	This category speaks to the importance of providing a clear description of the potential outcomes of an activity.	Observation activity

Experiential activities

Based on our observations and the school teachers' statements, the students in this age group were quite easily distracted and lost their concentration, interest and active engagement in the activities. Consequently, course materials and activities that engage them well are fundamental in developing an effective design thinking course, and using an interactive teaching style through a "show and tell" strategy engages students better (Aflatoony et al., 2017). According to Dixson (2010), student engagement not only relies on the type of activity, but also on multiple ways of creating meaningful communication and interactions between students, instructors and course content. According to our observations and interview sessions with the students and teachers, bodystorming, observation and the field trip were successful because students were fully engaged in them; the activities were playful and invited discovery. In fact, in those activities we did not observe any particular issue in the students' engagement or lack of concentration, and the majority of them were satisfied about being involved in the activity. The reason for their satisfaction lies in the fact that they interacted with each other and the course content when doing the activities. Students worked on group projects together, and they engaged in open discussion where they commented on one another's work during or after each activity.

This category also speaks to the nature of the materials and instructions provided in the course. For example, tactile activities and the open-ended nature of those activities could be

beneficial in teaching a successful design thinking course. The tactile activities can engage students and enable them to learn and present their ideas in a different format; the open-ended nature of activities gives students more freedom to choose their own path, thereby encouraging a sense of ownership (Aflatoony et al., 2017).

Real-world applications

The students preferred activities that clearly illustrated the practical implementation of the techniques or activities they were learning during the course. For example, they enjoyed having a guest speaker, observing their school environment and going on a tour of SIAT (field trip) (Figure 6). These activities made their learning experiences even more meaningful as they could connect their knowledge and experiences gained in the classroom to real-world situations. This is in line with Discovery learning, an inquiry-based, constructivist learning theory that takes place in problem-solving situations that invite learners to interact with the world through exploration and the manipulation of objects. Consequently, students are more likely to remember concepts because they discovered them on their own (Bruner 2009).

According to our earlier findings (Aflatoony et al., 2015), teaching the *entire design-thinking process* was beneficial for students in a variety of ways. Creating relevant and connected course activities inside and outside the classroom made the learning process and its content more meaningful for students. In contrast, the lack of connection (e.g. among different assignments, concepts, activities) can result in distraction and confusion, negatively impacting the students' learning progression. Students are typically curious, and they constantly seek answers to their questions. Connecting the course content to real-life situations can answer many of their questions by providing more logical and tangible solutions.

Characterised consequences

Finally, the students learned when they had a reason to learn; in other words, when they could clearly see the learning outcomes of an activity. For example, the students did not perform well in the sketchbook activity because they were not quite sure about the main reasons for and outcomes of the assignments. Lack of sufficient explanation about tasks or activities can cause students to have a lack of interest, engagement or motivation for completing an activity, as we experienced and observed with the sketchbook activity. In the observation activity, the students knew the outcomes and expectations clearly before engaging in the activity (find missing parts of the space descriptions); they also knew what they were supposed to do during the activity, and the next step they had to take after completing the activity. Therefore, the students had a clear mental map of how to accomplish their tasks; they were more determined and they performed much better during this activity. Providing the instruction early on before starting an activity saved time in the learning process and prevented potential confusion. While in the importance of providing a learning goal has been well-established in other educational contexts, here we emphasise and confirm its significance in teaching problem-based or even less-structured informal curricula.

Figure 6. Students were most satisfied when attending the field trip and observation activity, and having a guest speaker in the course.

Discussion and limitations of the study

According to this study's findings, the above-mentioned activities and instruction encouraged the *active participation of students* in course concepts. This is in-line with Discovery learning theory, which encourages active engagement of students by promoting motivation, responsibility and independence: all characteristics that we observed in the students' actions and reactions in the classroom. In all cases, the students were more determined to complete all the activities; they also performed better and generated excellent work, as demonstrated by their submissions and presentations.

In the experiential activities category, the students enjoyed activities that enabled them to explore a concept by physically engaging in the activity. The real-world applications spoke to the necessity of connecting the course content to the outside world in order to make it more comprehensible for students. With regards to the third curriculum characteristic, clarifying an activity's learning outcomes was substantially helpful to the students. The lack of such an explanation may result in the failure of an activity, as we experienced with the sketchbook activity. Moreover, as we explained in a separate research study (Aflatoony et al. 2017), providing clear, step-by-step instructions for how to complete an activity through *visual representations* is beneficial for this age group. Hence, we found clarity to be an essential factor in both the course instructions and the course outcomes; it facilitates the students' concentration and encourages them to be truly present (physically and mentally) in the classroom, which can be supported through visual representations. This is related to the notion of social presence and the degree of awareness in a communicative setting (Short et al. 1976; Rice 1993). While the notion of social presence is a fundamental requirement of distance education, it might be suitable to apply it to improve instructional effectiveness in other settings.

The instructor encouraged the students' critical thinking through ongoing reflections and discussions during the lectures and presentations. To assess students' understanding of concepts such as ubiquitous computing, he asked specific questions, such as "How many of you use YouTube on your phone? Would you write your paper on a mobile device?" We found this strategy to be successful in encouraging the students' critical thinking and facilitating their active participation in the course activities. Asking questions about issues that students encountered during the course also helped them understand the issue in a different way. This strategy enabled them to be reflective and critically think about their own learning processes.

This study had some limitations in terms of course implementation and evaluation. The main challenge that the school teachers encountered in the course was assessing the students' learning outcomes based on the International Baccalaureate (IB) model. The interaction design thinking course was part of a larger course at both of the schools in this study, so that required the teachers to provide a decisive evaluation of the learning outcomes. Furthermore, the teachers found it challenging to incorporate the course content into the IB framework.

Conclusion and future work

In this paper, we provided an analytical lens for modifying and implementing a design thinking curriculum for grade 9 and grade 10 students. Several steps were taken to appropriately select, modify and implement the curriculum into a new setting, and to evaluate the success or failure of the curriculum itself. Consequently, we proposed a design thinking curriculum that motivated and engaged students with the course contents, and we provided applicable recommendations for design educators when implementing a design thinking-based pedagogy. Three curriculum characteristics were found to be essential when choosing activities for a design thinking curriculum: 1) experiential activities, 2) real-world applications and 3) characterised consequences.

There are several directions for extending this work. First, it would be worthwhile to incorporate the curriculum into a larger public school setting, or to involve more than two schools. Second, it would be worthwhile to investigate how to apply design-thinking techniques and practices to non-design courses (e.g. geography, mathematics) and provide

recommendations for school teachers on the benefits of using design thinking in teaching STEM courses, and more specifically, how to implement it in a non-design course.

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