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From Teacher-Designer to Student-Researcher: a Study of Attitude Change Regarding Creativity in STEAM Education by Using *Makey Makey* as a Platform for Human-Centred Design Instrument

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Abstract
The purpose of this study was to examine creative thinking and learning in arts-infused education by using the invention kit *Makey Makey* as a platform for Human-Centred Design Instrument (HCDI). Data were collected from 249 adolescents ($n = 249$) from a Hong Kong secondary school in a participatory design format. They were selected for the STEAM project, which is provided through the school curriculum to examine the level of attitude change towards creativity through the creation of human-centred musical instruments for different age cohorts, including children (aged 3–6), adults and elderly people (aged over 65). The research objectives were concerned with the development of collaborative creative thinking through an HCDI and with how students combined and transformed new knowledge for everyday application with meaning – a breakthrough in musical instrument design for human needs. Questionnaires, observation and interviews were conducted to examine the students' level of creative thinking. Based on a modification of the creativity measurement framework from the Runco Ideational Behavior Scale (RIBS), a significant increase in the attitude change of students' creativity was shown from the paired-sample t-test in the dimensions of originality, flexibility, fluency and elaboration through the STEAM project.

Keywords STEAM education · Creative thinking · Human-centred design instrument · *Makey Makey* · Arts-infused education

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Introduction

Science, Technology, Engineering and Mathematics (STEM) education has increasingly been applied in curricula in recent years but is regarded as bounded within particular disciplines. Creative thinking is required in order to effect a shift away from methods that marginalise art education, and thus to progress instead to Science, Technology, Engineering, Art and Mathematics (STEAM) education. Arts-infused education can provide students with experiences to connect knowledge with meaning in the real world context, shifting from computational thinking to human-centred learning. Arts integration is important, as it can lead students to develop in new directions, and can help determine how and to what extent educators can instil a new kind of transdisciplinary learning, which facilitates creative thinking, within the relevant community. In the Hong Kong context, inadequate instructional teaching materials and a lack of professional teacher training are the main obstacles to delivering the STEAM project curriculum. The objective of this research was to study the development of collaborative creative thinking through a Human-Centred Design Instrument (HCDI) and how students combined and transformed new knowledge into everyday applications with meaning – an innovation in musical instrument design for human needs.

The current study marks a critical step in this direction by drawing attention to the role of teachers and exploring possible research directions. This can enable the construction of a curriculum design pedagogical framework for teacher training in arts education, along with the conceptualisation of a learning-thinking model in future STEAM education.

The current study was guided by the following research questions:

1. How can the HCDI be used as a tool in STEAM education?
2. How do students' attitudes with regard to creative thinking change through the making of HCDIs in arts-infused education?

Theoretical Background

Creative Thinking

Creative thinking is a complex process that may take place in many fields and pursuits, both of which affect students' learning. In general, creative thinking can be defined as the 'interaction among aptitude, process, and environment by which an individual or group produces a perceptible product that is both novel and useful as designed within a social context' (Plucker et al. 2004, p. 90).

Creative thinking allows students to consider diverse concepts in a subjective manner, leading to inventive ideas. Views about creative thinking in music education have changed over the generations. Webster (1990) defined the creative process as creative thinking and later divided the concept into the two areas of personal and social-cultural (Webster 2011; 2016). This is aligned with Csikszentmihalyi (1999), who suggested that creative thinking occurs at the interaction between a person's thoughts and their socio-cultural context. Process is more valued and collaborative creativity more focused in creative thinking, as opposed to the conceptual understanding within the individual-based knowledge of facts (Webster 1990, 2002). Children's culture is viewed as distinct and directly influences the development of creative products rather than following and adapting adult-generated culture (James et al., 1998; Corsaro 2000). Kampylis and Berki (2014, p. 6) stated that creative thinking enables students to apply their imaginations to generate ideas, questions and hypotheses and to experiment with alternatives and evaluate their own and their peers' ideas, final products and processes. Students can act as designers of knowledge through creativity and interactively collaborate with influences in the social environment (Boy 2013). Through the exchange of knowledge in the process of creative thinking among peers, students can develop the ability to generate a number of possible solutions from different perspectives and then select the best one. It is an ideal teaching strategy for students to develop creative thinking skills through class discussion, and for unanticipated, novel ideas to then be developed through teachers' cultivation and active pursuit (Beghetto 2007). This can stimulate critical thinking and pave the way towards developing and changing social norms for future generations. However, this is particularly relevant that Chinese teachers may hinder students' creativity as expressive behaviour can be interpreted as rebellious (Chan and Chan 1999; Kaufman and Beghetto 2013).

STEAM Education

It has been suggested that STEM education should shift towards the implementation of STEAM, in line with the sustainable development of education goals in the twenty-first century.

In the Hong Kong context, STEM education was first proposed in 2015 and further highlighted in the 2016 Policy Address, which concerned the renewal of the school curriculum. The aim was to equip Hong Kong students with the knowledge required to nurture their critical thinking across disciplines, and to develop the ability to integrate and apply their knowledge of science, technology, engineering and mathematics in solving actual problems in everyday life. This type of learning process can facilitate life-long learning, and help develop well-rounded individuals, which is the ultimate goal in education (EDB 2015).

The STEAM concept, whereby the Arts (A), along with design, assume their central position through their incorporation of student learning across the other four disciplines, was developed by the Rhode Island School of Design (RISD) in the US (RISD 2013). The final report by the Department for Culture, Media and Sport (DCMS) Select Committee in the UK stated that arts subjects in a modern education system should be recognised as crucial and thus added to the STEM subjects, likewise changing the four-letter STEM to the five-letter STEAM (DCMS 2013). Technical knowledge is not sufficient when living in an evolving society. Combining the aesthetic sense and sensory experiences stimulates human thinking and affects how identity is formed. Unique ideas will then be produced, and these ideas represent the output of creativity (Diehl and Stroebe 1987). In STEAM education, students are expected to not only learn expert knowledge within a discipline but are also trained to break through boundaries and make connections between disciplines based on individual knowledge, experience and sense through arts-infused education. By bringing these elements together, students may connect through a deeper and unique understanding in a holistic manner via the integration of disciplines. This may lead to newly constructed ideas resulting from the creative process. This connection is crucial for the development of skills in real-life problem solving, and may affect the level of creative thinking and innovation in students' learning.

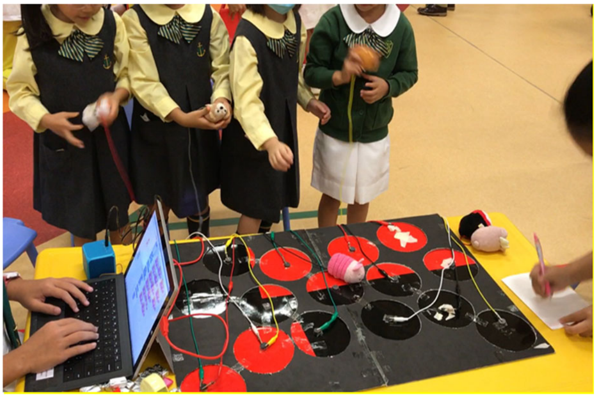
STEAM education has become increasingly popular worldwide in recent years, and studies have found that most educators support this integrated strategy to a large extent (Han and Lee 2012). Its positive impact on students' thinking and learning beyond traditional disciplines is generally recognised, through practical solutions that are connected to everyday life (Henriksen 2014)). In Asian countries such as Korea, the majority of teachers view STEAM education as necessary in fulfilling the demands of the twenty-first century. However, it is lamentable that only around 18% of teachers are able to implement STEAM lessons (Shin 2013). A similar situation is found in Hong Kong, as there are no concrete guidelines on STEAM education from the Hong Kong Education Bureau. Ng (2017) pointed out that Hong Kong is already falling behind in STEM education, not to mention STEAM. He claimed that model answers, exam skills and strategies dominated the whole education system. As things currently stand, the implementation of both the STEM and STEAM curricula are hampered by the pedagogical methods of teachers; these are essentially concerned with delivering technical knowledge to students while ignoring the necessity of raising their motivation to innovate. Aside from curriculum development, insufficient teacher training is another major concern. An article from MingPao (2018) reported that school principals in Hong Kong still tended to focus on teachers' academic qualifications, rather than the flexibility of their pedagogical approaches. Moreover, teachers who have been employed by schools for a number of years find it difficult to follow new trends, preferring instead to delegate teaching of the STEM program to STEM-expert teachers. As a result, some primary schools have hired up to six secondary level science teachers to teach STEM subjects. The lack of a coherent education policy has led to insufficient teaching expertise when implementing the lessons. Thus, an enormous gap between education policy and actual practices has thus been identified in the promotion of STEAM education.

Human-Centred Design Instrument (HCDI)

In human-centred design the needs and abilities of the users are emphasised. Norman (2005) stated that human-centred design is 'one designs something for people with a deep, detailed knowledge of those people…' The principle of human-centred design instruments (HCDI) is that technology should adapt to the person. It is a practice that involves people collaborating on ideas that may create value for society. Human-centred design principles are applied to a variety of social issues, leading to many public sector innovations (OECD 2017), and they help to improve both usability and understanding. Baum (2016) stated that Human-Centred Design Instruments (HCDI) are 'support of making things better for people'. It is worthwhile drawing attention to the mindsets of HCDI designers, as they are able to examine the constraints of reality and explore the possible range of conditions within which humans are able to function (Norman 2005). Due to radical technological developments in the twenty-first century, the conception of human interaction has progressively shifted from a focus on the traditional usage of a programming computer tool for productivity enhancement to the use of a more accessible and interactive interface, in the service of expanding the scope and range of computer-mediated human activities that can facilitate more sophisticated and unique tasks (Stephanidis 2001). The main aim of such design is to put people first, wherein human experience, interactions and perspectives are accounted for throughout the process of co-creation; in this way, creative minds from diverse disciplines can be encouraged to participate and work together in order to come up with ways of doing things differently in order to create impact (UNICEF 2016). Putting this philosophy into the education context, HCDIs may allow people from all walks of life to participate in music and help create solutions to problems in music education without simply focusing on traditional composition and performance. A new direction in arts education is thus offered, removing the barriers for those who are not equipped with musical skills so that they can also enjoy playing musical instruments and get involved in music making. The HCDI combines the world of technology with knowledge transfer, stimulating the imagination through the creative process and recognising the potential of the interface to deliver personal aesthetics for unique innovation, thereby leading to the aim of education – learning for life (Picture 1).

Makey Makey Invention Kit

Makey Makey is an invention kit that transforms any material that can conduct an electrical current into a physical interface for any software (Collective and Shaw 2012). It has been used as a tool or a teaching aid in numerous research projects focusing on ideas generation through technology involvement for younger or older individuals. Rogers and his team applied *Makey Makey* in a creativity workshop with a group of retired people between 60 and 90 years old (Rogers et al. 2014). By linking the conductive objects with the provided alligator clips instead of using the computer keyboard, the user can creatively design a tactile and human-centred interface that allows both beginners and experts to get involved in music-making. It was observed that the elderly were willing to accept the challenges, and invention occurred when they freely shared their ideas and their situated knowledge. This increased their motivation to learn more about technology. The tool can thus encourage people from all walks of



Picture 1 The design of the human-centred design instrument (HCDI)

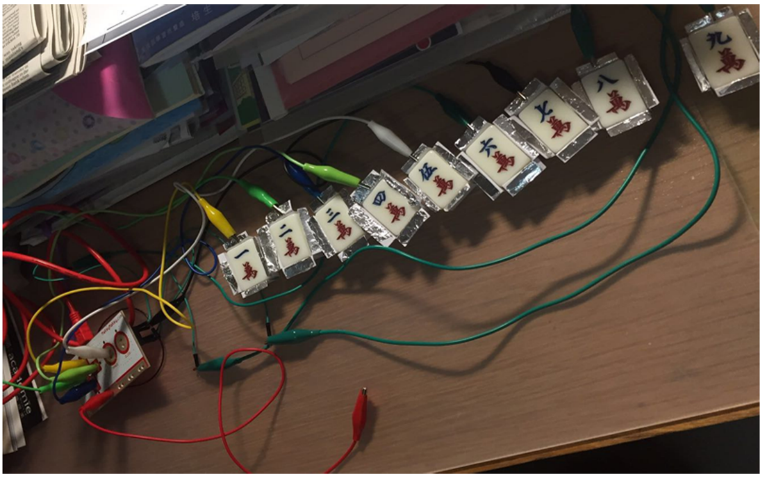
life to become more involved in creative technology through everyday experience. Moving from STEM to STEAM education with the help of *Makey Makey*, students in a classroom setting can brainstorm their interactive and artistic ideas collaboratively through mastering the technology (Rogers et al. 2014), which acts as an experimental platform for students to participate in practical innovation through self-expression (Siemon et al. 2016) (Picture 2).

Research Design and Methods

Research Design

Our goal was to gather data to measure differences in the levels of students' attitude towards creative thinking by designing Human-Centred Design Instruments (HCDI) for different age cohorts in the STEAM project. A pilot study was conducted and a mixed-method approach used to gain a good understanding of the complex process of facilitating creative thinking, from creative learning to real world application, through STEAM education.

Data were collected via three sources: (1) an online survey, (2) class observation, and; (3) individual interviews with the teachers in charge of the STEAM project. Through the use of multiple data collection methods such as questionnaires, observations, interviews and information from the participating students, kindergarten students and teachers in charge of the STEAM project, multiple reference points that informed the analysis and interpretation of the data were provided (Stake 1995). This allows for flexibility that can extend the line of inquiry to interpreting multiple sources, thus providing a more focused view of this complex phenomenon in a natural setting and filling the gap in the acquired related data (Creswell 1998).



Picture 2 *Makey Makey* invention kit

Participants and Settings

Data were collected from 249 adolescents ($n = 249$) from a Hong Kong secondary school. Students from Secondary 1 classes aged between 11 and 13 were involved in the mode of participation by designing the instructional sequence. They were selected for the STEAM project, which is provided through the school curriculum, to examine the level of creative thinking through the creation of human-centred musical instruments for different age cohorts including children (aged 3–6), adults and elderly people (aged over 65). Students were divided into several groups and participated in a series of activities in the classroom setting, ranging from an introductory course on how to use the *Makey Makey* Tool Kit to how to design and create the HCDI with the Tool Kit for different age cohorts. The curriculum design and the setting of the STEAM class were divided into 3 parts across 8 weeks as follows (Table 1):

Data Collection and Measurement

The data for this study was derived from the questionnaire, which was set as a self-evaluation questions for each student to focus on the quantitative measurement of the divergent thinking that takes place in the creative thinking process. The Runco Ideational Behavior Scale (RIBS) was used with modifications from the framework of the attitude towards creativity in the idea creation process from Runco et al. (2001) to direct the investigation of the research question 'How do students change creative thinking through HCDI in arts education?' The ideation behaviour of the students can be examined to gain a better understanding of their everyday creativity. The RIBS can be used as a criterion of creative ideation for both children and non-professionals through a self-report measurement of personal assessment of creativity. The scale contained 21 modified close-ended items about ideation as product and divergent thinking, which were assessed using 5-point Likert scales ranging from 1, 'strongly disagree', to 5, 'strongly agree'. The survey was classified into the four main dimensions of (1) Originality (*Q* 1, 5, 7, 10, 17 and 21), (2) Flexibility (*Q* 6, 8, 14, 16, 19 and

Table 1 The three stages of the STEAM project

Stage	Aim
1st session - Introductory stage	• To deliver the students the invention kit *Makey Makey* and the software *Scratch* • To provide opportunities for students to get hands-on experience coding the musical notes and programming the sound by connecting the alligator clips from *Makey Makey* with the online programming software *Scratch,* thus creating a *Makey Makey* instrument.
2nd session - Exploration stage	• To explore the conductive materials in groups and generate ideas for the HCDI with the *Makey Makey* Tool Kit. • To combine the collaborative ideas and design the HCDI with the set of constraints for the assigned age cohort.
3rd session - Experimental stage	• To show how the designed instruments function and how to apply them to the assigned age cohort through simple demonstration. • HCDI trial run at the kindergarten.

20), (3) Fluency (*Q* 2, 4, 12, 13, 15 and 18) and (4) Elaboration for creative thinking (*Q* 3, 9 and 11), all of which were considered as creative thinking strategies that reflected students' abilities in the process of brainstorming and connecting ideas, eventually leading to the creative product (Guilford 1950; Gorder 1980; Webster, 1994; Runco et al. 2001; Kharkhurin 2008). The RIBS scale was further correlated with happiness, creative ideation and locus of control. It was found that happiness was predicted to be correlated with creative ideation. (Pannells and Claxton 2008).

The items in the survey reflect openness to divergent attitudes, which support creative thinking (Runco et al. 2001). A survey was carried out to determine whether there were any changes in attitudes towards creativity between the adult group – and the children and the elderly group. Attitude changes regarding creativity of both groups can also be simultaneously assessed to ascertain whether there is any significant difference in the four dimensions through HCDI in arts education.

Students' self-ratings, in the same form in which the STEAM project was recorded. The difference between their retrospective pre- and post-ratings reflects the perceived impact of their creative thinking after designing the human-centred musical instruments. The participants' current levels of self-assessment were noted to create a common measuring indicator for pre- and post-assessments at the end of the related tasks, which could help to ensure consistency (Hiebert et al. 2011).

Class observation was arranged to investigate the feasibility of incorporating *Makey Makey* into the STEAM curriculum. The students were assigned the target of designing the human-centred musical instruments in groups for adults, kids and the elderly. The basic outline of the lesson plan was as follows (Table 2):

An additional non-participant observation was tested at the kindergarten and lasted for approximately one hour. One secondary 1 class ($n = 40$) was involved in the study. The observation was conducted in a naturalistic setting with no adjustment made by the teachers or researchers. It was video-recorded for analysis of the behavioural patterns of the participants and to establish how the two kindergarten classes ($n = 30$) students, as the users, enjoyed and learnt through the HCDI with the guidance of the Form 1 students as the creators.

Open-ended interviews were conducted with the teachers in charge to explore their perceptions of the students' engagement and the role of the teachers in the STEAM project using the *Makey Makey* toolkit. These can be used to determine the role of teachers and further explore the pedagogical framework in arts-infused education for teacher training to conceptualise and enhance the efficiency of the learning-thinking model in STEAM education.

Results

Online Survey

As shown in Table 3, Cronbach's alpha analysis was used to determine the reliability of the close-ended questions of the survey instrument both pre- and post-test. Cronbach's alphas for the components of attitudes towards creativity in *Originality* (6 items), *Flexibility* (6 items), *Fluency* (6 items) and *Elaboration for creative thinking* (3 items)

Table 2 Lesson plan of the STEAM project

Lesson 1 (60 min)	Task: Create a *Makey Makey* Piano instrument • Introduction - Play the video and introduce *Makey Makey* - Use *Scratch* to code the notes produced when different notes are pressed - Teacher briefly explains the codes (most codes are given to the students) - Students try to play music using the assigned key in s*Scratch* • Making the instruments - Student use a piece of white paper and some aluminium foil to make the notes of a piano - Connect the alligator clips to the aluminium foil keys on the piano - Students try out their own classroom-made piano and may improvise short tunes with the use of *Makey Makey* through the online program *Scratch*
Lesson 2 (60 min)	Task: Create own *Makey Makey* Musical instrument • Discovery/Exploration Stage - 5–6 students in a group - Bring the prepared materials and try out different conductive materials with the connection of *Makey Makey* - Discuss and generate ideas for the design of the musical instruments - Set up their own kit with the desired materials - Try to improvise a short tune with the newly designed musical instruments • Collaborative Performance Stage - Play a song in class as an ensemble with their newly designed instruments - Students share their experience and give feedback on the performance/design - Vote for the best performing group at the end
Lesson 3 (60 min)	Task: Create Human-Centred Musical Instruments (HCDI) for Different Age Cohorts • Idea Generation - Form students into groups and discuss the characteristics of different age cohorts (ie kids, adults and the elderly) in terms of personality, level of musical knowledge, diversity of skill sets, level of experience and preference in technology - Each group is responsible for one targeted age cohort. - Encourage students to focus on the particular needs of each targeted age cohort. - Discuss the ideas in groups and set the constraints of the respective age cohort. - Combine the collaborative ideas and assign students to design the musical instruments with the connection of *Makey Makey* kit by using different prepared materials for different age cohorts Group I: Young students Group II: Adults Group III: Elderly
Lesson 4 (60 min)	Task: Experiment and demonstration • Present the design ideas in groups after collaborative discussion • Explain the rationale for how the newly created instrument fits the target group • Show how the designed instruments functions and how to apply to targeted age cohort through simple demonstration For example, The 'Young students' cohort will give an HCDI trial run at kindergarten and invite the young children to play the instruments. • Reflection on the process of creating Human-Centred Musical Instruments (Self-evaluation of creative thinking) • Teachers give comments to each group after their presentations

were .95, .945, .934 and .929, respectively. The results were highly consistent across the variables, suggesting excellent reliability for the data collected in this study ($\alpha = .937$) for all 21 items in the survey.

Table 3 Items of the creativity measurement and its internal consistency reliability

Ideational behaviour scale adopted with modification from the framework of the creativity measurement from the Runco Ideational Behavior Scale (2001)	
Originality	
1. I have many creative ideas when participating in STEAM-*Makey Makey* activities.	
5. I come up with an idea or solution that other people have never thought of.	
7. I consider that it is important to be able to think of extraordinary and unique possibilities.	
10. I am interested in participating in the STEAM-*Makey Makey* project, which is based on your own ideas.	
17. I am able to think up answers to problems that I could not figure out before.	
21. I have ideas about new inventions or how to further improve the STEAM-*Makey Makey* project.	
Cronbach's alpha (6 items)	.95
Flexibility	
6. I like to play around with ideas for the fun of it.	
8. I would rate myself highly at being able to come up with different kinds of ideas.	
14. I often find that one of my ideas has further led me to other ideas, and I end up with an idea but I do not know where it comes from.	
16. I try to think the STEAM-*Makey Makey* project from different perspectives.	
19. I am good at combining ideas in different ways that others have not tried.	
20. My groupmates ask me to help them think of ideas and solutions.	
Cronbach's alpha (6 items)	.945
Fluency	
1. The number of ideas that I may offer is more than those of the other groupmates.	
4. I come up with a lot of ideas for problem solving during the discussion in the STEAM-*Makey Makey* project.	
12. Sometimes I feel so interested in a new idea that I forget about other things.	
13. When having discussions with groupmates in class, I often have trouble staying with one topic because I think of so many things to express.	
15. I may develop a variety of ideas at once.	
18. I have always been an active thinker – I have lots of ideas.	
Cronbach's alpha (6 items)	.934
Elaboration for creative thinking	
3. I often get excited by my own new ideas in the STEAM-*Makey Makey* project.	
9. I enjoy the freedom to make up my own mind and brainstorm the ideas in the STEAM-*Makey Makey* project.	
11. I am able to concentrate on the newly designed STEAM-*Makey Makey* creation.	
Cronbach's alpha (3 items)	.929

Table 4 further examines students' levels of self-assessment in attitude towards creativity under different situations in real world settings. Group A (secondary school students create HCDI for Adult) and Group B (secondary school students create HCDI for Children and Elderly) showed significant increases from the pre-test to the post-test in the dimensions of *Originality, Flexibility, Fluency* and *Elaboration*. Among these four dimensions, the highest mean score in *Originality* was found in Group B

Table 4 Paired sample t-test of Group A (Adult) and Group B (Children and Elderly) in different dimensions of creative thinking

Dimensions		Pre-test	Post-test	df	t	Sig.	d
Originality	Group A (*n* = 90)	17.96 (4.532)	19.09 (4.926)	89	4.571	.000	.24
	Group B (*n* = 159)	18.62 (4.318)	19.40 (4.650)	158	4.764	.000	.17
Flexibility	Group A	17.73 (4.522)	18.62 (4.893)	89	4.176	.000	.19
	Group B	18.57 (4.207)	19.35 (4.634)	158	5.281	.000	.16
Fluency	Group A	17.18 (4.242)	17.82 (4.228)	89	2.699	.008	.15
	Group B	18.13 (4.411)	18.84 (4.743)	158	4.705	.000	.15
Elaboration for creative thinking	Group A	8.88 (2.430)	9.39 (2.871)	89	3.704	.000	.19
	Group B	9.52 (2.415)	9.82 (2.591)	158	3.201	.002	.12
All	Group A	61.74 (14.824)	64.92 (16.145)	89	4.496	.000	.20
	Group B	64.84 (14.619)	67.41 (15.817)	158	5.810	.000	.17

(M = 19.4), t(158) = 4.764, $p < .001$, d = .17 in the post-test result, with a mean difference of 0.78 within the group, after accounting for the pre-test score (M = 18.62). These data showed that Group B students who designed the HCDI demonstrated a distinct increase in their level of attitude change towards creative thinking, particularly in the dimension of *Originality*, through the application of situated knowledge in everyday life.

Table 5 uses comparisons to examine students' levels of attitude difference regarding creative thinking under different situations in 'real-world context'. As such, there were no significant differences between Group A (Adult) and the Group B (Children and Elderly) in most of the dimensions, except for *Elaboration for creative thinking* in pre-test. Here, the independent-samples t-test indicated that the scores were significantly higher for Group B (M = 9.52, SD = 2.415) than for Group A (M = 8.88, SD = 2.430), t(247) = 2.018, $p < .05$, d = .26.

Table 5 Independent sample t-test of Group A (Adult) and Group B (Children and Elderly) in different dimensions of creative thinking

Dimensions		Group A (*n* = 90)	Group B (*n* = 159)	df	t	Sig.	d
Originality	Pre-test	17.96 (4.532)	18.62 (4.318)	247	−1.140	.256	.15
	Post-test	19.09 (4.926)	19.40 (4.650)	247	−.490	.624	.07
Flexibility	Pre-test	17.73 (4.522)	18.57 (4.207)	247	−1.460	.146	.19
	Post-test	18.62 (4.893)	19.35 (4.634)	247	−1.170	.243	.15
Fluency	Pre-test	17.18 (4.242)	18.13 (4.411)	247	−1.663	.098	.22
	Post-test	17.82 (4.228)	18.84 (4.743)	247	−1.685	.093	.22
Elaboration for creative thinking	Pre-test	8.88 (2.430)	9.52 (2.415)	247	−2.018	.045	.26
	Post-test	9.39 (2.871)	9.82 (2.591)	247	−1.223	.222	.16
All	Pre-test	61.74 (14.824)	64.84 (14.619)	247	−1.595	.112	.21
	Post-test	64.92 (16.145)	67.41 (15.817)	247	−1.183	.238	.16

Observation

Verbal and observational data were generated during the school visit in each of the Introductory, Exploration and Experimental stages in the implementation of the STEAM project. Three on-site visits were arranged for each stage, as shown in the Table 6 below (Table 6).

Interview

A focus group interview with one teacher in charge was arranged after the implementation of the STEAM project. There was no concrete pedagogical framework and guidelines for the teachers to follow. The main obstacle to implementing the STEAM project was the delivery of cross-disciplinary material instead of their own discipline. They felt anxious, as they had no prior experience teaching STEAM. They faced various kinds of challenges when designing the curriculum:

a) Teachers' self-preparation

> "*We find it difficult to learn something new, especially tasks involving programming. Moreover, we will feel anxious if the module is abstract.*"

b) Students' learning objectives

> "*We think it is quite difficult. We have to adjust it constantly. We try to adjust the teaching and learning pace and content for each individual class based on students' ability and interest.*"

Table 6 Class observation of each stage in the STEAM project

Stages	Students' response in the STEAM project
First visit - Introductory stage	Students showed different levels in applying the *Makey Makey*. The Kids cohort focused more on the musical structure and sound effects, while the Elderly cohort focused on the technical connection, including the circuit setup and programming.
Second visit - Exploration stage	Students were asked to design a human-centred instrument for different age cohorts and collaborated on ideas that were generated from the group discussion. The Elderly cohort created Chinese opera, and their focus point was more on the process, including music making and application. The Children cohort created nursery games, e.g., sponge ball and airplane jump. They focused on the product, including the appearance of the HCDI, in order to attract other children to get in touch with it.
Third visit - Experimental stage	Students gave an HCDI trial to younger students at the kindergarten. Children actively participated in the activities and were able to improvise simple tunes through play and movement without any prior knowledge by following the instructions of the F1 students as student-researchers.

Not surprisingly, the views from teachers on insufficient training align with the literature review. Some teachers found it difficult to learn the new technology, such as the new programme, 'Scratch', in turn struggling to set clear learning objectives according to their students' capabilities. To compensate, they kept trying to fine-tune the teaching content and modify the learning pace based on students' diverse abilities in each class. To promote students' attitude changes towards creativity, concepts of design elements and humanity were highlighted. Guiding questions concerning the features and basic needs of the related target groups were discussed with students during teaching. The teacher in charge shared his teaching strategies as follows:

> "*We tried to adopt the idea of design thinking into the module. Once students are assigned with different groups, then they were guided to think about the features of the group and also their needs. Since student's ability is quite diverse, we encouraged students to focus on one of their needs. For example, for those who were working on adult, we encouraged students to narrow down to which type of adult they are thinking about. For example, if you want to have a design for an office executive who wants to learn music instruments after work, what are their needs? We then also suggested them to think about some samples around them, like their parents and relatives.*"

This group designed a kit for Human-Centred DesignedInstrument to assist adults in playing music without difficulties while reading the music score. The students were able to apply their situated knowledge to their own creation. In the teaching stage, the teachers' emphasis was on stimulating attitude changes in students' creativity together in the design thinking process. For example, the first priority for any group of people had to be the practicality of the instrument; while many imaginative suggestions might be generated during the discussion stage, the features that distinguished the assigned targeted group was their ability to narrow down their ideas in order to come up with a more suitable design for the target group. In this way, students could refine their designs and raise the level of practicality.

The teachers agreed that the students were able to achieve the learning objectives and the results matched their expectations. In other words, all the students managed to finish making a musical instrument for the target group. However, they also pointed out that some students overestimated their claims, resulting in an outcome which was not as good as they expected. For example, the young students group found that some children were unable to handle playing their instruments well since the parts were too small in the trial run at the kindergarten. From the teachers' perspective, it was nevertheless good to see that the students kept improving and reflecting upon their actions throughout the activities.

Discussion and Implication

Human-Centred Design Thinking

This study reveals how students generated ideas and developed creative thinking processes through the use of the *Makey Makey* invention kit as part of a STEAM project. It was observed that most students were able to apply their personal experiences in response to music making with the use of the *Makey Makey* tool kit. This project helped them broaden their thinking, and they moved towards becoming creators who were able to actively explore the possibilities needed to generate unique innovative ideas and design human-centred musical instruments. Those without prior musical knowledge were also able to engage in music making through this particular use of technology. As a result, the 'A' in STEAM education through integrated arts-infused teaching and learning was successfully achieved.

In this study, it was observed that the participants were motivated to think from different perspectives and to combine ideas in different ways that had not previously been attempted. In particular, a noticeable increase (mean difference: 0.17) in the level of *Flexibility* was exhibited after they participated in the STEAM project. As Norman (2005) has stated, in order to have a more positive impact on society, human-centred design should focus on 'knowing your user' with deep or detailed knowledge in specific situations.

Research-Based Pedagogies in STEAM Education

In the Hong Kong context, as the teachers noted, the current challenge in striving for successful change to promote students' creative thinking in practice is the lack of guidelines and standardised teaching materials for STEAM education. Teachers are expected to be the major stakeholders in broadening the pedagogical framework and implementing a curriculum that leads to the acquisition of knowledge transfer from the classroom to the realm of practice through on-going experience (Stein 1998). In reality, however, the quality and implementation of the STEAM curriculum depends on individual teachers' knowledge, beliefs and attitudes. Most Hong Kong teachers are not familiar with the teaching direction or are not well equipped with the teaching content, and they find it hard to collaborate with specialised teachers from other disciplines. Many in-service teachers lack confidence in teaching out-of-the-box and hesitate when it comes to implementing new STEAM pedagogies.

It is important for educators to inspire students to figure out what they want to know and to be active learners for self-learning. From the participants' perspective, it was assumed that the use of the *Makey Makey* toolkit would allow the individuals to think about how to play, learn and design for themselves. They were guided as diverse inventors in different age cohorts through technology. One implication of this study is that the traditional teacher-student relationship has changed in STEAM education to one between 'teacher-designers' and 'student-researchers'. The role of STEAM teachers acts as a curriculum designer and the role of students in STEAM education act as a researcher in the teaching and learning of STEAM classroom. An approach that replaces traditional 'knowledge-based' with 'research-based' pedagogies is thus one direction suggested by STEAM education.

Measurement of Attitude Change Regarding Creativity in STEAM Education

To stimulate students' attitude changes when it comes to creative thinking in STEAM education, it is suggested that research-based pedagogies should develop towards student-centred activities through exploration with the aid of integrated technology. This helps shift the roles of teachers to 'teacher-designers' and 'student-researchers' and motivates them to participate in collaborative peer discussions with the acquired skills and knowledge. Based on the students' level of interest and active participation in the STEAM project, it was observed that they were able to generate ideas about new inventions or make further improvements in the project. There was an obvious increase in the level of *Originality* on the part of the participants, showing that they brainstormed many creative ideas (*Q*1) and were able to think of extraordinary and unique possibilities in the STEAM-*Makey Makey* project (*Q*7). The students' level of engagement in this study clearly demonstrated their ability and confidence in mastering the invention toolkit, which gave them a strong inquiry-based learning impetus, rather than simply seeking leisure and entertainment. From the teachers' perspective, students' creative thinking can be further stimulated by providing guidance questions and setting constraints when they apply the contextual knowledge in the real world (Kaufman and Beghetto 2013), an observation which ties in with both the observation in this study and research literature.

In this study, the framework of self-perceptions of creativity from the Runco Ideational Behavior Scale (2001) was adopted. To facilitate future development in STEAM education research, an assessment tool in this study was developed to measure students' attitude change towards creativity by calculating the quantitative differences between individuals before and after the STEAM projects. This can provide a better understanding of what kinds of projects best suit the students, as well as deciding which can be used in curriculum design and to refine the implementation of each project.

To conclude, it is essential to guide students towards figuring out problems or challenges in real-world contexts and to encourage them to be open-minded in creating solutions to human needs through instant sharing among peers with the aid of invention toolkits. This can provide meaningful effects in life in alignment with the direction for innovation in youth empowerment as proposed by UNICEF (UNICEF 2016).

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An Explanation of Why your Manuscript Should Be Published in the Journal for STEM Education Research This manuscript should be published in the JSER because this article is about STEAM education and students' creativity. This article is both cutting edge and the first of its kind in this field. It fits really well with the aims of the journal about study of students' learning, psychological, and cognitive development in STEAM education. Also, the role of Arts-infused education is obscure. This article will be a good exemplar to examine how STEAM relates to the RIBS scale in creative thinking as a research assessment tool.

An Explanation of any Issues Relating to Journal Policies This manuscript investigated the pedagogical implications such as the changing role of teacher designer and student researcher in curriculum design and established the new practices within technology-rich learning environment by using Makey Makey as a human-centred design instrument. This study will have a significant global impact in STEAM education with an innovative pedagogy and objective measurement in creativity.

Compliance with Ethical Standards

Ethical Approval This study was approved by the Human Ethical Review Committee (HERC) of the University. A consent form was provided and signed by the participants and their parents before the research was conducted.

Conflict of Interest Statement The researchers do not have any conflict of interest with the product, Makey Makey in this study.

Confirmation Statement I confirmed that all authors have approved the manuscript for submission and the content of the manuscript has not been published, or submitted for publication elsewhere.

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