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Enhancing student creativity through an interdisciplinary, project-oriented problem-based learning undergraduate curriculum

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A R T I C L E I N F O

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A B S T R A C T

To develop the creativity needed to confront the multi-faceted challenges of 21st Century sustainable development goals (SDGs), university students urgently need a curriculum framed around their solving real-world problems, such as what a Project-Oriented, Problem-Based Learning (POPBL) curriculum offers. Moreover, to build a functionally sustainable future, students should develop creativity through an interdisciplinary lens. This study used a quasi-experimental design to explore the impact of an interdisciplinary POPBL course with a participatory design pedagogy on university students' engineering creativity. Four professors from future studies, architecture, engineering, and education disciplines designed and implemented the experimental curriculum. The curriculum incorporated three key concepts around creative design thinking: participatory design, future thinking, and visual communication. The experimental group consisted of 19 undergraduate students in the Engineering Design for Society course. The control group of 23 Civil Engineering undergraduates participated in the Civil Engineering Design course. The findings are: (1) The experimental group received significantly higher creativity scores on fluency, flexibility, originality, and usefulness. (2) The control group's scores regressed on the post-test. (3) The experimental group's higher scores indicated that interdisciplinary POPBL instruction combined with participatory design pedagogy can promote interdisciplinary creativity. The researchers propose the term *empathetic-future thinking* to describe the participatory design pedagogy centred on community-based feedback and interdisciplinary communication and teamwork. By developing a sense of empathy for cross-domain cognition and the end-users of the design, students enhanced the originality and usefulness of their design. Educators should incorporate *empathetic-future thinking* to develop students' engineering creativity for achieving 21st Century SDGs.

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1. Introduction

Despite universities setting or adopting Sustainable Development Goals (SDGs), many have yet to develop curricula to comprehensively teach or practically implement these goals (Filho et al., 2019). Design and engineering university students need a curriculum which addresses the challenges for their tomorrow. Specifically, a curriculum which engages students to think creatively across disciplines as part of the unprecedented challenges and opportunities of design and engineering in the 21st Century (van Laar et al., 2019). However, educators often poorly understand or implement creativity instruction, leading to explanatory instruction rather than practical instruction intertwining disciplines and concepts; educators uncreatively and merely 'explain' the process of 'creativity' (Mróz & Ocetkiewicz, 2021; Tran et al., 2017). This occurs despite ample research suggesting that Project-Oriented, Problem-Based Learning (POPBL) effectively helps students ascertain creativity and sustainability principles (Lehmann et al., 2008; Wan Husin et al., 2016; Yasin & Rahman, 2011). Hence, there is a specific need to re-examine the curriculum and discipline which educators use to teach undergraduate students creativity, and more specifically tune those curricula to creativity and solving 21st Century engineering and design challenges.

1.1. Overview of POPBL and interdisciplinary courses

Creativity within the curriculum is not so much a thing that educators 'instruct' as much as help students 'learn' the process of completing a task creatively. Paradoxically, the level of 'creativity' is only known once the end-product of a project shows the originality, uniqueness, and effectiveness of that thing. Creativity is not truly creative unless it breaks the mould of habitual concepts, merely identifying a problem, and habit bias (Simonton, 2018). Yet, psychologically, most people perceive 'creativity' differently; thus, educators will perceive the same differences, ascribing more importance to certain values of creativity than other educators (Glück et al., 2002) . Thus, any such curriculum needs the backing of a strong sense of collaboration and guidance in the creative assembly of original experiences, very much where the educators exhibit creativity (Runco & Jaeger, 2012).

Interdisciplinary courses offer a strong sense of developing creativity within the curriculum and enabling such within the practice. Interdisciplinary courses help students improve teamwork, communication, and critical thinking skills. Students work through an interdisciplinary perspective, supplying an original and unique setting, to create innovative and effective solutions for practical problems (Cotantino et al., 2010; Klaassen, 2018). Specifically, these courses should focus on developing students' practice and attention in a real-world environment and against real problems (Chang et al., 2000; Kuo et al., 2019). The goal of utilising POPBL as instructing creativity is, after all, to directly influence problem solving skills for future challenges.

Universities currently widely use POPBL courses with much success (Fini, et al., 2018; McLoone, et al., 2014). POPBL allows different groups of students in a course to work together to solve practical problems and to present and defend their approaches and solutions. The work requires them to actively participate in the process of acquiring and applying knowledge. Yasin et al. (2009) indicated that POPBL not only focuses on deriving solutions that have practical influence on social issues, but also promotes students' creativity. Thus, interdisciplinary POPBL curricula is one of the powerful ways to cultivate students' critical thinking and engineering creativity.

1.2. Objectives

Although POPBL is a well-researched and supported method of practice, the novelty of this study design is to focus on creating a general education course for undergraduate students which combines POPBL curriculum with an interdisciplinary design focusing on enhancing students' creativity for addressing their communities' 21st century future challenges. This study focuses on instructing Taiwanese university students through an interdisciplinary lens by assigning them tasks in addressing future climate and urban issues in two districts in Taipei, their country's capital. Moreover, this paper focuses on the challenge by including a participatory design framework; that is, the researchers implement the POPBL aspects outside of the classroom, where students work to develop empathy for their users by receiving feedback from the community while focusing on future thinking. This paper meets these challenges by following two objectives throughout the research process:

1) Introduce a new instruction framework centred on participatory design by combining research-supported POPBL teaching practices to enhance student creativity in solving 21st Century sustainability challenges.
2) Develop a reliable instrument for assessing student's engineering creativity which follows the principles of participatory design.

2. Literature review

2.1. Definitions of creativity

Guilford (1950) proposed the definition of creativity as a mental task demanding novel concepts. Torrance (1974) applied Guilford's creativity theory to draw a framework for creative thinking processes consisting of four aspects: fluency, flexibility, originality, and elaboration. Fluency refers to the production of a great number of ideas or alternate solutions to a problem. Flexibility refers to the production of ideas that show multiple possibilities or realms of thought. Originality involves the production of ideas that are novel. Elaboration is the process of enhancing ideas by providing more detail. Further, Sternberg and Lubart (1999) stressed that creativity produces content that is novel while being appropriate to the situational demands. Hence, originality and functionality intertwine.

Creativity also must intrinsically carry a functional use or efficiency. Engineers achieve creativity more explicitly through 'functional creativity'; that is, products which service both a functional and pragmatic purpose (Cropley & Cropley, 2005). Thus, engineering problem identification is one of the key steps in the process of problem-solving; both of which fit the definition of increasing creative production (Srinivasan & Kraslawski, 2006). Hence, engineering for creativity is not only addressing aesthetics like artists, but preventing potential problems while solving problems in a novel yet functional way (Charyton, 2013; Cotantino et al., 2010; Simonton, 2018). This full scope of creativity is what modern courses in general education should intertwine to teach students creative employment of sustainability, future-thinking, and engineering for creativity (Cropley & Cropley, 2005; Kuo et al., 2019). This study has adapted Torrance's four dimensions (fluency, flexibility, originality, and elaboration) and usefulness as the central theoretical framework of creativity. The aim is to identify educational curriculum which can enhance student's creativity.

2.2. *POPBL within an interdisciplinary course*

The basic principles of POPBL are as follows: (1) Student-centred programmes which motivate and gain commitment among students; (2) Problem- oriented and not subject-oriented; (3) Students find a solution through the learning process rather than recalling knowledge; (4) Project-Based which has a goal and action component to derive change; (5) Exemplarity instead of generality; (6) Promote group teamwork, social and communication skills (Yasin & Rahman, 2011). Implementing an interdisciplinary POPBL course starts with the analysis of a research problem followed by project design which implements interdisciplinary activity to derive a solution (Yasin & Rahman, 2011).

An interdisciplinary course complements the professional knowledge among different educators to develop innovative pedagogy (Wang & Lo, 2014). One of the most common ways of developing an interdisciplinary course is to focus on addressing practical problems in society (Wu & Yeh, 2003). Educators identifying the most pressing problems for engineering students to solve creates a focused environment for students. The curriculum horizontally and vertically integrated related concepts of each discipline with the thematic concept of a societal problem as the centre. Educators from different professional fields execute the project theme (i.e., the central problem identified), while the teaching-concepts from interdisciplinary subjects integrate the differing professional knowledge.

One of the effective methods to teach POPBL for 21st Century creative thinking – such as sustainability – is the design thinking approach (Callahan, 2019; von Thienen et al., 2017). Design thinking refers to the human-oriented problem-solving methodology, seeking innovative solutions for various issues and creating more possibilities through human needs (Brown, 2008; Callahan, 2019). However, researchers and practitioners of design thinking apply and define design thinking differently (Micheli et al., 2019). The model of Design Thinking originates from Herbert Simon's *The Sciences of the Artificial,* in which he originally indicated that design thinking was divided into two parts: firstly, in the empathy phase, people from different fields think divergently and explore various issues; secondly, in the ideate phase, everyone from different fields think to find possible solution, propose various possible solutions, integrate different solutions and find the most suitable way to present the prototype (Simon, 1999). The Hasso Plattner Institute of Design (2010) at Stanford defined the processes of design thinking as following: (1) Empathise: Human-centred and divergent thinking; (2) Define: Converging the problems of the previous stage, identifying the core needs of users, and then defining core issues; (3) Ideate: Creating various ways to solve problems and help users solve problems; (4) Prototype: Using existing resources to test and start making prototypes; (5) Test: Looking for subjects to experience and complete the project. Another way to define design thinking consists of combining divergent and convergent thinking into a creative process (Yasin, et al., 2009). However, these definitions and concepts do not have to work against one another. Design thinking has potential to work as a broader field of definitions, which work to evolve different concepts of creative design and thinking (Johansson-Sköldberg et al., 2013). To effectively harness the creative undertones of design thinking while employing specific and consistent instruction, this study largely adopts the Hasso Plattner definition of design thinking as a core philosophical axis for students to implement, study, and practice inside of POPBL.

3. Method

3.1. *Procedure*

This study used the quasi-experimental design, utilising a control group to compare with the experimental group. However, the study did not follow true random selection of participants due to the organizational system of classes at the university. Both groups' tasks emphasised 21st Century 'creativity' skills; the core curriculum and instruction differed. Before the course, the students took a pre-course assessment. Following the final of each course, students took a post-test assessment. Since the instrument created is novel, section 3.4 addresses the assessment process and score analysis.

3.2. *Participants*

The participants were 42 undergraduate students in a public university in Taipei, Taiwan. The experimental group consisted of 19 undergraduate students who chose (i.e., not specifically invited) to enrol in the "Engineering Design for Society" course, which utilised the experimental interdisciplinary POPBL course, focusing on participatory design and enhancing students' creativity. The control group of 23 civil engineering students took another course titled "Civil Engineering Design" and received the standard engineering instruction which is part of the standard curriculum instructed for 'engineering creativity'. Table 1 displays the demographics of the experimental and control groups.

3.3. Teaching design

Four professors from different fields – civil engineering, future studies, architecture, and education – designed and taught the interdisciplinary POPBL curriculum. The professor from education did not instruct the students, but designed the assessment instrument herein. The design thinking approach promoted students' creativity, teamwork, and critical thinking. The POPBL oriented curriculum asked students to complete a social-space problem solution project for a real-world field task. The real-world geographic locations in this course were the Nanfuli (南福里) and Longfuli (龍福里) areas in the Zhongzheng District of Taipei City. These local areas used to be a Japanese civil servant residential area before 1945 and thus include historic sites, traditional Chinese buildings, art and historic museums, and numerous business stores such as vintage postal stores, old book stalls and furniture houses.

3.3.1. Teaching pedagogy

The professors asked the students to work as a team to design a city plan to modify these sensitive, multicultural, and historical areas. The professors guided the students to integrate futures thinking methods and participatory design in creative problem-solving. Students had to observe how residents of these areas moved about and functioned in life to meet the requirement of participatory design; resident's behaviour had to be a factor in their design for sustainability. Students had to think 30-50 years ahead while keeping today's residents, culture, and historical value in-mind. Moreover, residents needed enough space to live, but also enough innovation to enhance their living standards as sustainability issues (specifically drought and changing weather patterns in Taiwan) complicate urban design. At the end of the semester, students made city plan proposals for their social-space problem solutions. The community and experts provided feedback and suggestions on students' proposals.

This course aimed for students to learn about 1) interdisciplinary work and cross-domain teamwork, 2) future thinking, and improving the ability to think beyond the existing framework, 3) Learn the concepts of participatory design, improving multi-faceted analysis, 4) develop creative problem-solving thinking. The course consisted of 17 weeks, including four weekends spent conducting field work measures and a fifth final weekend for designing and constructing the final. Fig. 1 presents the outline of the semester, translated from the original Mandarin in the syllabus.

3.4. Instrument

The Engineering Creativity Scale (ECS) assessed students' creativity. Torrance's (1974) definition of creativity including fluency, flexibility, originality, and elaboration influenced the theoretical framework for assessment. Moreover, Design Thinking from the Hasso Plattner Institute of Design (2010) definition influenced the dimensions of aesthetic and functional needs and solving and preventing problems (Charyton, 2013). To avoid the carry-over effect of pre-test on the participants, this study created two parallel ECS forms: Form A and Form B. Form A served as the pre-test and Form B as the post-test. Form A consisted of two sub-tests: "Design a product that generates sound" and "Design a car." Form B consisted of two sub-tests: "Design a product for communication" and "Design a bus stop".

"Design a product that generates sound" asked participants to draw two designs (Design 1 and Design 2) based on two 3-dimension images. The questionnaire asked participants to describe each of their two designs by answering the following questions: (1) What is your design? (2) What are the materials of your designs? (3) What are the problems solved with your designs? (4) Who will be users of your designs? The second subtest, "Design a car", required participants to draw a car with their creativity. Concurrently, the participants described the features and specifics of the car they designed. The test was meant for group administration and asked the participants to draw their creative products by pens. The test time allotted was 30 minutes: 10 minutes for "Design a product that generates sound" and 20 minutes for "Design a car". Form B's testing system was the same as Form A, only with different tasks: "Design a product for communication," and "Design a bus stop."

3.4.1. Instrument scoring

Four engineering creativity experts scored the participants' answers with the following procedural steps. The (A) "Design a product that generates sound" and (B) "Design a product for communication," assessments consisted of four dimensions: fluency, flexibility,

Table 1
Demographics data for participants.

Demographics	Experimental		Control		Total	
	n	%	*n*	%	*N*	%
Gender						
Male	13	68.42	15	65.22	28	66.67
Female	6	31.58	8	34.78	14	33.33
Academic Year						
Freshman	4	21.05	0	0	4	9.52
Sophomore	1	5.26	0	0	1	2.38
Junior	4	21.05	18	78.26	22	52.38
Senior	6	31.58	4	17.39	10	23.81
Fifth year	4	21.05	1	4.35	5	11.90
Total	19	100	23	100	42	100

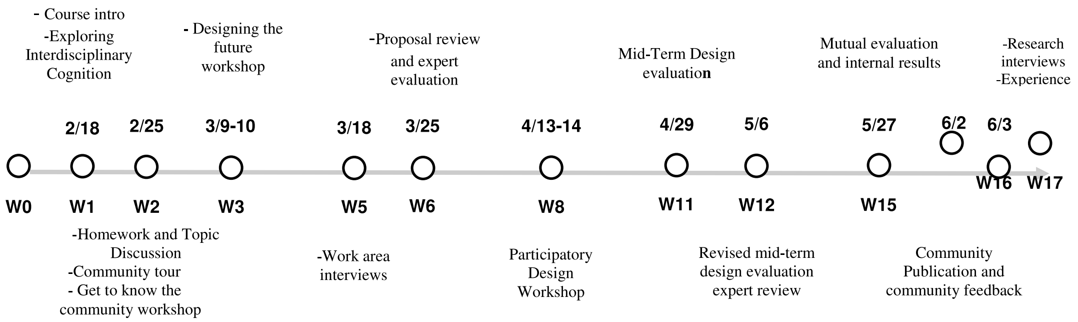

Fig. 1. Syllabus course progression and work schedule.

originality, and usefulness. The number of ideas on the sketch, description, materials, problems solved, and user functionality computed the fluency score. The number of different categories, types, or classifications of responses computed the flexibility score. The experts assessed the originality on an 11-point scale. A 5-point scale computed the usefulness of the design. The experts scored Design 1 and Design 2 separately, and then they computed the sum of Design 1 and Design 2 for each dimension, separately.

The (A) "Design a Car" and (B) "Design a bus stop" assessments included four dimensions: fluency, flexibility, originality, and elaboration. The experts scored fluency by counting all the valid responses given by the subjects. The experts scored flexibility by counting the total number of feature categories that were on the car. A tabulation of the frequency of all the responses obtained computed the originality score. The experts computed the frequency and percentage of each response occurring within the entire set of student responses. After tabulating all responses, a special answer for the originality score where the probability of a student providing that answer on the assessment was smaller than 1.99% received two points. An answer where the probability of a student providing that answer on the assessment was between 2% and 4.99% received one point. The elaboration score consisted of counting the numbers of specific car details provided by the subjects.

The total score for (A) "Design a product that generates sound" and (B) "Design a product for communication," respectively, for each participant was computed by summing individuals' scores for fluency, flexibility, originality, and usefulness. The total score for (A) "Design a car" and (B) "Design a bus stop," respectively, was computed by summing the scores of fluency, flexibility, originality, and elaboration. The total score for engineering creativity for each subject was computed by averaging scores of these two subtests' scores.

3.4.2. Data analysis

The one-way analysis of covariance with $\alpha = .05$ (pre-test score as covariate) was employed to explore the difference between the experimental group and control group in each dimension of the ECS scores.

The coefficients of inter-rater reliability were between .47-.97, $p < .001$ and the test/re-test reliability coefficients were between .44–.56, $p < .05$).

4. Results

Table 2 presents the means and standard deviations of the pre-test and post-test scores on each dimension of the ECS in the experimental and control group. Table 2 also shows the results of ANCOVA. Table 2 demonstrates there were significant differences

Table 2
ANCOVA Results and descriptive statistics for creativity scores by instruction type.

Dimension	group		*Pre-test*		Post-test		*Adj.M*	*F*
		n	*M*	*SD*	*M*	*SD*		
Fluency	Experimental	19	48.20[a]	6.19	52.40	5.85	52.86	12.23*
	Control	23	50.92	5.99	47.09	5.70	46.71	
Flexibility	Experimental	19	48.76	6.40	51.59	6.68	52.07	4.37*
	Control	23	51.18	6.13	48.13	6.79	47.73	
Originality	Experimental	19	49.63	6.28	52.89	6.52	52.94	18.56***
	Control	23	48.39	5.03	45.47	4.56	45.43	
Elaboration	Experimental	19	48.93	10.60	50.44	10.10	50.61	.52
	Control	23	50.06	7.17	48.54	10.06	48.40	
Usefulness	Experimental	19	49.86	11.04	53.41	8.33	53.39	7.13*
	Control	23	49.50	7.88	46.12	8.99	46.13	
Total	Experimental	19	48.99	5.16	52.20	5.73	52.38	10.38**
	Control	23	50.07	4.06	47.00	5.48	46.86	

Note: a: T score; $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

between groups in the dimensions of fluency ($F = 12.23$, $p < .05$), flexibility ($F = 4.37$, $p < .05$), originality ($F = 18.56$, $p < .001$), and usefulness ($F = 10.38$, $p < .05$). However, the experimental group and control group showed no significant difference on the elaboration dimension ($F = .52$). The overall adjusted mean showed the experimental group reported significantly higher scores ($F = 10.38$, $p < .01$).

Notably, on the pre-test, the control group performed better. However, on the post-test, not only did the experimental group perform better, but the control group's scores dropped so sharply the adjusted mean for both tests showed that the experimental group had significantly higher scores on the above-mentioned dimensions. Hence, the experimental group was working from 'less' engineering creativity in the beginning. This carries implications for the success of the interdisciplinary course to deliver creativity and, urgently, the lack thereof for standardised civil engineering design courses. The results revealed that the "Interdisciplinary Social Engineering Design for Society" in this study could promote participants' creativity within the dimensions of fluency, flexibility, fluency, flexibility, and originality.

5. Discussion

The study results provide important contributions to the theory and practice of innovation in teaching creativity. Moreover, reflections on innovating 'regular' engineering courses to ensure they include original creativity are also important to making pragmatic changes in courses; moving successful 'experimental' courses into regular course work. The interdisciplinary efforts to developing the curriculum offer a refined method for students to problem-solve in POPBL courses while learning how to apply participatory-design principles into the broader spectrum of instruction.

5.1. Validity of ECS assessment

The first contribution pertains to the applicability and validity of the ECS assessment for capturing learning outcomes pertaining to creativity in engineering. Using both pre-test and post-test data, the empirical findings suggest that the ECS assessment is a reliable instrument for assessment of student learning outcomes. Moreover, coefficients of inter-rater reliability (.47-.97, $p < .001$) and the test/re-test reliability coefficients (.44–.56, $p < .05$) suggest a reliable assessment. Students' responses reflected the attributes of creativity (Torrance, 1974) through their ability to create new engineering paradigms, and not a standard response sheet. By utilising a score sheet which reflected their ability to create functional design, the assessment directly reflected the workshops in which they designed functional items for the community. Furthermore, expert engineers scored the assessment to confirm that the designs were practical engineering items, not only 'creative' items that lacked the required engineering pragmatism. Future assessments, both for research and in-class assessments, should reflect student's functional and pragmatic creativity through the medium of creation, not checking boxes to evaluate 'right' scores. Moreover, the validation of this assessment recommends the utilisation of experts to ensure future reliability when developing new assessment scales. Experts assisted in the validity process, helping to alleviate scorer and teaching bias while implementing the interdisciplinary principles of future-thinking and engineering in the scoring process.

The corner stone of the assessment relies on the design-thinking oriented principles therein. The ECS asked both engineering and the non-engineering students to develop principled and creative designs that focused on multiple aspects. The students in the interdisciplinary course showed they had developed creativity and understanding of how to design and fix problems on a reliable form that broached multiple principles of creativity and design-thinking.

5.2. Interdisciplinary POPBL

The second contribution of the study pertains to the impact of interdisciplinary POPBL on the improvement of key dimensions of students' creativity and learning outcomes. While previous studies have shown improvement in student learning outcomes by using POPBL in civil engineering courses (Yasin & Rahman, 2011), this study showed the effect of pragmatic interdisciplinary POPBL that focused on workshops and instructing real-world engineering. Through the utilisation of multiple professors from different backgrounds, the curriculum addressed sustainability within the context of tomorrow's challenges. Students had to develop knowledge and creative skills within multiple contexts to succeed at the course; the post-test results showed their success. Moreover, these students' displayed better creativity than the engineering course – a core curriculum which aims to elicit creativity for civil engineers. This may result from the combination of the interdisciplinary skills and the project-oriented, problem-based learning. That is, interdisciplinary curriculum fits squarely into project-oriented curriculum as students will continue their interdisciplinary knowledge-growth as they work in teams (Holley, 2017).

One of the chief organisation principles of the curriculum which benefitted students' individual growth may have been their teamwork and communication (Yasin & Rahman, 2011). Empirical findings show significant improvement in student learning outcomes in engineering creativity through the application of teamwork and communication skills, both on the students' and professors' ends. Moreover, one new pedagogical tool herein was the inclusion of dedicated time to interview the community the students designed in. By spending time interviewing and working within these communities, students also developed communication skills that could translate to designing with communication and community in mind, thus building empathy. Compared to designing simply for engineering design, including interviews with the community translated to designs that integrated with people in mind. Hence, students in the experimental group scored significantly higher on usefulness – possibly a reflection of designing with humans in mind – and originality – extracting ideas from the community outside of the traditional engineering paradigm. Originality is not solely reflected from an individual's concepts, but interviewing and reflecting on the practical users' opinions can infuse users with original designs. This also reflects the real-world need of identifying a problem within a community – engineers cannot simply create a product for a problem they identify and hope to build a brand; future-thinking engineers build a better product when they engage with the community to identify pragmatic challenges and create pragmatic functional and original designs to solve those problems.

Thus, future research ought to focus on the intersection between interdisciplinary teamwork and creativity, with an emphasis on POPBL that integrates community-partnerships. POPBL enhances students' creativity; however, POPBL pedagogy which integrates students into researching the community to ascertain original problems and thus original solutions may benefit students more than a traditional problem of an outwards-lens POPBL based solely in the classroom. Moreover, research can enhance the 'teamwork' aspect of interdisciplinary, creative learning to ascertain the role communication plays within the POPBL pedagogy and research.

The context of the project – city planning in future thinking – is also critical to the pedagogy. The professors incorporated tasks which developed students' understanding of problem-solving in realistic, and prescient, scenarios. Future students – regardless of engineer or not – will confront city planning for sustainability within Taiwan's historic districts; this is a job which requires many different fields to address (a la medical access, engineering, security, energy, etc.). Developing interdisciplinary perspectives of cities may have been another factor benefitting the students' originality. Not only did students develop originality in their design work from interviews and pragmatic situations, but through the practice of thinking through the multiple fields and problems which must work together to solve future-challenges. Future POPBL pedagogy ought to include problems which develop demand interdisciplinary perspectives to identify original, real-world situations. POPBL pedagogy which moves out of the classroom enhances participatory design, inclusive of interdisciplinary work.

Moreover, not only did the experimental students' show higher creativity on the post-test assessment, the Civil Engineering students' creativity scores dropped below the pre-test scores of the experimental class. The most significant reason this could be is the engineering students were seeking to provide the 'textbook' answer to the ECS assessment. Current Engineering Design courses thus may be stifling creativity and encouraging students to provide uniform answers; that is, engineering courses which provide students' mono-discipline and in-classroom assignments prevent students from exploring paradigms which enhance originality, usefulness, flexibility, and fluency. Engineering students may exhibit principled engineering as the course requires, but without a pragmatic and interdisciplinary POPBL course which invites students into the real-world challenges non-engineering thinking users face for their current, and future reality, engineering students simply explore a singular framework. Even in normal POPBL courses, which many engineering courses now exhibit, engineering students may not benefit from the interdisciplinary dynamics of interviewing and thus assessing needs the textbook, or the courses, did not expect. The post-test originality score supports this hypothesis, which was the lowest score (Control: M =45.47, Experimental: $M = 52.89$) of all scores for the control group. Not only this, but the standard deviation was 4.56, the smallest *SD* in both groups pre- and post-tests. That is, students in the traditional engineering class gave fewer original answers *after* taking the course and provided more homogenous answers. Considering the challenges tomorrow engineer's will face, it is thus imperative engineering courses adopt an interdisciplinary and problem-based approach that focuses on ascertaining original, real-world challenges.

5.3. Development of creativity

The third contribution of this study pertains to the success of the experimental group. Creating an interdisciplinary learning environment improved students' teamwork, collaboration, and communication while encouraging students to look beyond the normal framework of a design course. Creativity improved not merely aesthetically, but functionally. For sustainability and developmental goals, this functional creativity is one of the critical aspects of creativity students ought to develop. The highest score for both groups on both tests was in-fact the experimental group's *Usefulness* score ($M = 53.41$). Particularly beneficial was likely the future studies aspect which encouraged 'participatory design.' This, again, reflects positively on the pedagogy which allowed students to work with the community and receive expert feedback, improving the usefulness of their designs. Moreover, students received feedback directly from the community in their course, not only disconnected experts. Including community feedback, and extending beyond the educators' rubric, is an important inclusion in the problem-solving part of the POPBL paradigm.

Furthermore, students had to directly solve for problems that demanded fluency (i.e., variety in the area's future designs), flexibility (i.e., willingness to adjust for the historical nature of the areas; architecture flexible to withstand change in time), originality (i.e., designs which were fresh to older districts yet were future-problem oriented), elaboration (i.e., explaining their designs comprehensively), and usefulness (i.e., ensuring it was useful for the future-city as well as today's residents). Educators who teach courses revolving around engineering and creativity should implement the successful pedagogy herein; chiefly intertwining community feedback and challenges within the pedagogy.

5.3.1. Development of empathetic-future thinking

Opposed to past studies (e.g., Chang et al., 2000; Kuo et al., 2019; Yasin, et al., 2009) this study went a step further in identifying the specific dimensions which creativity improves. Students not only had to focus on creating something that was beneficial to their lives, but to the community. That is, this project moved students out of the classroom and into the public arena where they had to consider community opinion while focusing on the pull of the past, present, and future in a historical area of Taipei.

Researchers often disagree what constitutes 'creativity' and how to assess it (Jahnke et al., 2017). Yet, one of the reservations on creativity is coursework often focuses on only producing *something* used by a non-specific audience, thus leaving students to reflect on how this item may affect them. Educators should not instruct the development of creativity through abstract conceptual tasks, rather, as this study shows, paradigms which involve moving outside of traditional frameworks. Creative items are truly creative when they break the box of self-conventional concepts and consider others' needs, both in the present and future. Hence, to teach students for sustainability, development, and future-thinking, students need to obtain an empathetic form of creativity. The pedagogy in this course intertwined developing empathy through interviewing for the community, receiving feedback from the community, and developing empathy in teamwork by partnering with colleagues across disciplines. The researchers propose this pedagogy is the development of *Empathetic-Future Thinking*, a design teaching pedagogy which focuses on enhancing creativity through the engagement with end-users. Educators and future researchers should pursue intertwining Empathetic-Future Thinking design pedagogy in future courses to develop students creativity for designing to the challenges present in 21st Century design (Razzouk & Shute, 2012).

6. Conclusions and implications

6.1. Conclusion

This study design assessed improvement in students' creativity through an interdisciplinary POPBL course that integrated real-community and sustainability challenges for the students. This research suggests that an interdisciplinary POPBL course improves students' design thinking-oriented creativity. Moreover, that educators include a pedagogy around *empathetic-future thinking*; that is, participatory design which integrates the community through interviews and direct-feedback – i.e., developing empathy for the people in need of design solutions – to improve students' creativity. Moreover, this paradigm is enhanced through teamwork within POPBL, suggesting cross-domain work enhances creativity through, again, empathetic teamwork and understanding interdisciplinary concepts. This suggests that interdisciplinary POPBL is an effective teaching and learning method that helps students relate course materials to functional practice while improving their level of understanding about the subject matter.

6.2. Implications

Interdisciplinary POPBL increases students' interest and their awareness of a subject. The interdisciplinary POPBL intervention allowed students to assess practical problems, learning the communication skills necessary to enhance creativity and empathetic design. Students engaged themselves and one another in future studies and future thinking. To enhance the instruction of 21st Century sustainability issues, educators should interject POPBL paradigms which leverage interviewing and communicating with those who receive the end-product; thus, students learn to design on feedback and with the end-user in mind.

6.3. Limitations

Sample size, inconsistent comparative groups, and non-random assignment limit this study. Although a quasi-experimental design, the enrolment process at the university did not allow for equal assigning in the compared-classes. Moreover, the researchers did not explicitly recruit students, but offered the experimental course as a one-time class within the general education curriculum; hence students form any department could register. The regular enrolment process could not be void for this research. Moreover, the researchers could not offer the students incentives, and thus several students dropped the course following the first week due to a longer, more intensive syllabus. Future studies should pursue a larger sample size to examine the impact of this pedagogical framework within the POPBL intervention. While increasing the sample size may not be practical due to the limitation on the number of students in a POPBL class, and their work within the community, increasing the sample size through administering the survey to several courses or over several semesters could provide the required sample size to conduct a more robust statistical analysis (e.g., Wu & Wu, 2020). Action research may offer pragmatic insight for such a creativity course focused on interdisciplinary learning and constructing 21st Century creativity skills (van Laar et al., 2019).

6.4. Future studies

Future studies can integrate qualitative data, such as classroom observation, educators' logs, and students' learning portfolios, to explore the different aspects of POPBL in an interdisciplinary course, and specifically empathetic-future thinking on students' creativity. This data will be essential to showcasing the finer details of how POPBL generates teamwork, communication, originally, functionality, and interpersonal skills. A course cannot be only the subject material, but all the tangible and intangible skills necessary for students to take action on the material.

Future research should also investigate the overlap between communication and creativity. Although the content orients around interdisciplinary activity, which interdisciplinary aspect – the educators' interaction or the student's interdisciplinary projects – had a bigger impact on creativity? Moreover, expanding on the ECS assessment herein will help to widen the application and access to additional creativity studies, focusing on enhancing creativity with future-thinking, design-thinking concepts.

CRediT authorship contribution statement

Te-Sheng Chang	1 Formulation of overarching research goals and aims
	2 Development and design of methodology
	3 Preparation and presentation of the published work

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(*continued*)

	4 Oversight and leadership responsibility for the research activity planning and execution, including mentorship external to the core team
	5 Management and coordination responsibility for the research activity planning and execution
Hung-Che Wang	1 Data/evidence collection
	2 Investigation, Conducting a research and investigation process, data collection
	3 Application of statistical data
Alexander MacDonald Haynes	1 Preparation, creation, and presentation of the published work
	2 Writing, Reviewing, and Editing
	3 Preparation, creation, and presentation of the published work, specifically visualization/ data presentation
Mei-Mei Song	1 Provision of study materials, teaching materials, and study participants.
	2 Verification of the overall reproducibility of experiments and research outputs.
Shih-Yao Lai	1 Provision of study materials, teaching materials, and study participants.
	2 Verification of the overall reproducibility of experiments and research outputs.
Shang-Hsien Hsieh	1 Provision of study materials, teaching materials, and study participants.
	2 Verification of the overall reproducibility of experiments and research outputs.

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Declaration of Competing Interest

The authors declare no competing interests involving the research conducted herein.

Data availability

The data that has been used is confidential.

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