An ISMP Approach for Promoting Design Innovation Capability and Its Interaction With Personal Characters

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ABSTRACT This article develops an instruction method for promoting design innovation capability through a design-based program with identification, modeling, simulation, and prototyping (IMSP). The computational thinking and conceptualization of sustainability were incorporated. The interaction between instruction treatment and participants’ personality was investigated. Eighty-six engineering undergraduates participated in this experimental study for exploring the effectiveness of the IMSP program. The findings indicate that 1) the IMSP program promoted undergraduates’ computational thinking, and further enhanced their design innovation ability; 2) the program that integrated the conceptualization of sustainability has better teaching effects than that without the conceptual integration; 3) the personal characters of innovation proaction and emotional intelligence acted as moderators in the ISMP program. This study presents a practical method for improving design innovation capability, and supports the feasibility and necessity of emphasizing computational thinking and sustainability in the innovation training program for engineering education.

INDEX TERMS Design innovation, computational thinking, conceptualization of sustainability, engineering education.

I. INTRODUCTION
Design innovation plays an increasingly important role in improving the competitiveness and sustainability of products and companies [1]. Design innovation refers to applying new concepts or technologies into the development of products or critical components [2], which requires both engineering experience and computational thinking [3], [4]. Although innovation capability involves individual interactions among various factors (e.g., educational background, working experience, family environment), personal characters are initially the essential factors affecting design innovation capability. This consensus drove academic and educational communities to incorporate personal characters into the empirical research of innovation ability development.

Previous researches in design capability development focused on the training of professional skills, such as the teaching strategy with a structured design process [5]–[7]. However, creativity generation is determined by a thinking process that avoids exploring engineering feasibility and detailed analysis of design results [8]. And the practice of applying computational thinking to assess design valubleness was often neglected. Thus, this study develops an instruction method for promoting students’ computational thinking and design capability that balances creativity and valubleness.

The educational community explores pedagogies with the integration of modeling, simulation, and other virtual prototype technologies [9], [10]. In this article, an IMSP design-based program is developed for fostering design innovation capability. The IMSP refers to an instruction program with four sections: problem identification, mechanism modeling, simulation, and prototyping. An actual design problem of a self-balance vehicle is proposed as the design task, in which the applications of design innovation and computational thinking were incorporated. Besides, the program emphasizes the direction of sustainable development through integrating the conceptualization of sustainability.
Although such an interdisciplinary study about innovation capability enhancement is few, a series of achievements have emerged in the study of the close relationships among computational thinking, simulation technology, and product sustainability [11]–[15]. The literature findings support that integrating computational thinking into the educational program may foster design innovation capability. Moreover, this study investigates the interaction between the ISMP program with participants’ personal characters of innovation proaction and emotional intelligence. Innovation proaction pertains to individual expectations or desire to discover innovative solutions for real-world challenges [16], [17]. Emotional intelligence refers to the personal character in the aspects of mood, emotion, will and frustration tolerance [18], [19].

Briefly, this article developed an instruction method of IMSP for promoting computational thinking and design innovation capability with the interaction analysis of personal characters. The conceptualization of sustainability was considered as a potential mechanism for improving teaching effects of the IMSP program.

II. LITERATURE REVIEW

A. INNOVATION, DESIGN AND COMPUTATIONAL THINKING

Innovation refers to the chain of events from creativity to new (or improved) products or services accepted by the market [2]. The design contains original concepts and valuable products, involving various disciplines and principles related to innovation. The design process requires the use of multidisciplinary theories and tools for taking into account the elements of innovation, such as creativity and valubleness. From this perspective, the design can be roughly be split into two types: creative design and instructional design [20]. Moreover, innovation involves a complex cognitive process. The literature emphasized the importance of studying the cognitive process of innovation in the educational program [21]. Design-based learning can promote innovation capability through experiencing design links such as problem identification, modeling, simulation, and prototyping [22], [23]. The research findings supported that innovation and design are closely related.

Computational thinking was defined as transforming real-world challenges into an easy-to-understand problem for computers, and achieve solutions through the operational skills of simplification, embedding, transformation, and simulation [24]. Seymour Papert (1996) firstly investigated computational thinking in terms of cognitive theory and empirical research [25]. Recently, the investigations of cognition interpretations of computational thinking have emerged. Ambrosio et al. (2014) developed a psychological assessment method based on programming activities to identify and measure the cognitive processes of computational thinking [26]. Aman et al. believe that computational thinking is a widely applicable competency for individual sustainable development in the current information society [27]. Román-González et al. proposed an evaluation method for computational thinking and explored the relationship between psychological traits with it [28]. They further deepened in this direction by extending non-cognitive factors related to computational thinking, such as self-efficacy, openness, conscientiousness, and agreeableness [29].

Design innovation seemingly provides continuous power for the sustainable development of modern society, focusing on solving real-world challenges [30]. Computational thinking is not only mathematical modeling, but also involves algorithm design, automation and generalization to other systems. Design innovation aims at problem exploration and valuable solutions for the requirements of the human and environment. Briefly, computational thinking is fundamental in design innovation, may improve the business value and sustainability of creativity.

B. DESIGN INNOVATION TRAINING WITH COMPUTER-BASED MODELING AND SIMULATION

Design innovation may become a new mindset to understand the contribution of emerging approaches, and a bridge to close the gap between advanced technology and market acceptance. It promises organizations to sustainable development with the advantage of meaningfully and satisfactorily responding to the changing consumer needs [2]. Puente et al. (2012) systematically reviewed the state-of-the-art empirical literature on design-based educational programs in higher engineering education. They found that embedding design tasks in open-ended, hands-on experiential, multidisciplinary, and authentic learning environments is a common feature of the reported programs. It was also suggested that a structured design process facilitates the thinking activities for proposing innovative solutions [23]. This article investigates the potential of incorporating problem simplification, creativity embedding, computer-based simulation, engineering transformation, and the conceptualization of sustainability, to improve design innovation capability.

With the rapid advancement of computer technology, modeling and simulation are increasingly embedded in product design processes [31]. It urges educators to integrate modeling and simulation training into higher education courses. Mladen et al. employed early modeling and simulation to enhance power engineering education [9]. More recently, Grepl (2011) reviewed available tools of modeling and simulation in terms of the usability, sampling-rate capability, and financial requirements in control engineering courses [32]. Zuo et al. proposed a framework from the linear finite element theory to educational software development, further extended this framework into nonlinear structural problems [33]. Bock and Yager developed a teaching tool based on data modeling worksheets for improving students’ ability to learn the extended entity-relationship data modeling principles [34]. These findings support the present study to apply modeling and simulation technology to enhance design innovation capability.

To promote the learning effects, the proposed IMSP program employed the following mechanisms: structured
design framework, guided discovery, self-assessment, and conceptualization of sustainability. A structured design framework refers to a paradigm that helps learners implement design tasks step by step. It guides learners through the zone of proximal development, that is a critical element of innovation capability development [35]. Guided discovery instruction has been suggested as a practical strategy for delivering complex concepts in engineering education [36]. In this program, students are encouraged and guided to experience scientific discovery, such as problem identification, simulation analysis, design verification, and prototype building. Self-assessment provides criteria to ensure that students can identify and adjust their thinking in the design activity. Finally, the conceptualization of sustainability refers to clarifying the concepts of sustainability involved in design innovation, such as various uncertainties in product development, potential demand, and other factors affecting sustainability [12], [13], [15].

C. EFFECTS OF INNOVATION PROACTION AND EMOTIONAL INTELLIGENCE

The theories of innovation suggested that personal characters are crucial for grasping design innovation skills [37]. This study attempts to elucidate the potential influences of two personal characters (i.e., innovation proaction and emotional intelligence) on individual innovation performance.

The moderating effect of proactive or initiative on learning has always been an important research topic in the field of pedagogy. Many studies suggested that intrinsic motivation is beneficial to various aspects of education, such as learning engagement, concept understanding, in-depth thinking, and capability development [38], [39]. Frese proposed the concept of “individual proactive behavior”, that is, a self-initiated work behavior that guides individuals to overcome difficulties for achieving organizational and personal goals [16]. Zhao et al. introduced the proactive behavior theory into innovation research and defined “innovation proaction” as voluntary behavior that fully prepares for practices and challenges in the innovation process. Further, they developed the Personnel innovation proaction Scale based on a quantitative analysis of 540 questionnaires [17].

Emotional intelligence broadly represents the ability to accurately perceive, evaluate, and express emotions, which may enhance design innovation performance. Schütte developed an approach of emotional engineering to improve understanding of the nature of products making an emotional impact on the customers, and efficiently translate the emotional agreement into product design solutions [40]. Agnoli et al. claimed emotional intelligence allows using the positive attention and emotion to promote creativity through regulating the feeling during the design process [41]. Because the nature of emotional intelligence lies in “emotion”, the role of emotional intelligence in the cultivation of innovation ability can be explained from the perspective of emotion. In a body of researches on cognitive processes about innovation capability, it is a consensus that passion and motivation can promote or regulate innovation processes [42], [43].

D. RESEARCH IDEAS OF THIS STUDY

In this study, the researchers proposed an instruction approach for enhancing students’ design innovation capability through the design-based program with a self-balance vehicle design task, where the application of design innovation and computational thinking was incorporated. The proposed approach was framed as the IMSP program. IMSP refers to the four instruction links involved in the design-based program: identification, modeling, simulation, prototyping. Identification is to simplify a real-world challenge into a design problem that can be understood by a computer. Modeling is to establish an analytical model of the variables or responses involved in the product design through mathematical or mechanics theory. Simulation refers to simulating the performance response of design options in the solving process. Prototyping is to transform the optimal design option into an engineering design result and further establish virtual or actual prototypes. Moreover, the conceptualization of sustainability was integrated into the training program. We speculated that the conceptualization of sustainability would improve teaching performance by enhanced active learning, and the IMSP program would promote students’ design innovation capability and computational thinking skills.

Besides, this study attempts to reveal the influence of personal characters of emotional intelligence and innovation proaction on the design innovation performance. This study examines whether there exists interaction effects between participants’ personal characters and the instruction treatment. Figure 1 shows the hypothetical model of the IMSP program influencing design innovation enhancement.

The following six hypotheses guided this study.

H1: The participants promote computational thinking after the ISMP program, with the participants experiencing conceptualization of sustainability outperforming those not experiencing that.

H2: The participants promote design capability after the ISMP program, with the participants experiencing conceptualization of sustainability outperforming those not experiencing that.

H3: Emotional intelligence is a moderator for design capability learning, and the participants with higher emotional intelligence outperform those with lower emotional intelligence in the design innovation performance.

H4: Innovation proaction is a moderator for design capability learning, and the participants with higher innovation proaction outperform those with lower innovation proaction in the design innovation performance.

H5: Emotional intelligence is a moderator for computational thinking learning, and the participants with higher emotional intelligence outperform those with
lower emotional intelligence in the performance of computational thinking.

H6: Innovation proaction is a moderator for computational thinking learning, and the participants with higher innovation proaction outperform those with lower innovation proaction in the performance of computational thinking.

III. METHODOLOGY

A. PARTICIPANTS

We implemented the experimental study in a design course, which is included in the undergraduate educational program for the mechanical engineering major at a comprehensive Chinese university. A total of eighty-six students from two teaching classes participated in this study. The sample composed of 69 males (79.3%) and 18 females (21.7%) with the mean age of 20.2 and the standard deviation of 0.64. According to the teaching class, the participants were naturally divided into the control group \((N = 42)\) or the experimental group \((N = 44)\). The class members were assigned randomly when the university enrolled them. Thus, it can be regarded as a random grouping. For satisfying the voluntary principle, we obtained the informed consent of each participant after stating the context of this experimental study.

B. LEARNING MATERIALS

The proposed IMSP program integrated the four components of identification, modeling, simulation, and prototyping. According to theories of constructivism and educational experience, the IMSP program was developed by the teaching team through months of literature research and discussion. The team members include a professor with over sixteen years of educational experience, two lecturers majoring in mechanical engineering, and a senior product designer. Two senior product managers reviewed the teaching materials in the IMSP program.

The four components of IMSP are explained as follows. (1) Identification: guide students to analyze a topic-specific design task and identify design objectives and constraints. (2) Modeling: instruct students to apply mathematical principles to formulate uncertainty models based on the samples of input parameters, and employ simulation software to create performance analysis models. (3) Solution: instruct students to establish a parametric design optimization model and solve it by programming. (4) Prototyping: guide students to transform the obtained theoretical option into engineering design, and build a corresponding virtual prototype. During the task implementation, the instructors provided purposeful guidance and formative feedback, and required students to make self-assessment and memos.

The task materials integrated multimedia, pictures, and texts. The multimedia was about the application scenarios and manufacturing process of the self-balance vehicle, provided by the real manufacturer. Thus, this challenge comes from the real world, requiring a design solution to improve product performance under uncertain conditions. The design task is to maximize the area of the self-balancing vehicle chassis, as Figure 2, while satisfying two constraints. The chassis is the supporting structure for the wheels, lamps, and control unit. A large chassis area leads to excellent driving stability, resulting in a favorable driving experience. The two constraints guarantee the vehicle driving stability under two typical conditions of turn and acceleration, respectively. Since the driving stability is determined by the vertical deformation of the chassis, the maximum deformation under the two conditions must be controlled. Inevitable manufacturing errors and random road excitation lead to various uncertainties involved in this design problem. These uncertainties may cause the fluctuation and decline of driving performance, and increase the failure probability during the design life, finally weaken the sustainability of the self-balance vehicle. For supporting uncertainty modeling, we provided 500 sets of sample data of uncertain valuables.

C. MEASURES

The teaching effects of the IMSP program were evaluated by two types of surveys: the tests and questionnaires (see Table 1). The tests referred to the pretest and posttest, which were respectively based on the design plan reports and design summary reports for the self-balance vehicle design task submitted by participants. They measured the performance of design innovation and computational thinking. Each test consisted of six items (see Table 2), including creativity, valuableness, simplification, embedding, simulation, and transformation. The test items also served as self-assessment.
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FIGURE 2. The design task of self-balance vehicle.

| Measures                     | Pretest and posttest based on design reports | Questionnaire of PIPS | Questionnaire of WLEIS | Questionnaire of Self-reflection |
|------------------------------|---------------------------------------------|-----------------------|------------------------|---------------------------------|
| Response options             | 1 (very week)                               | 1 (totally disagree)  | 1 (totally disagree)  | 1 (totally disagree)            |
|                             | ~ 5 (very strong)                           | ~ 5 (totally agree)   | ~ 5 (totally agree)   | ~ 5 (totally agree)             |
| Number of Dimensions & items | 2/6                                         | 6 / 22                | 4 / 16                 | 2/6                             |
|                             | ( see Table II )                            | ( Appendix A )        | ( Appendix B )         | ( see Table III )               |
| Dimensions                  | 1) Innovation design (2);                  | 1) Desire for innovation (5); | 1) Self emotion appraisal (4); |
|                             | 2) Computational thinking (4)              | 2) preparation for innovation (7); | 2) Others’ emotion appraisal (4); |
|                             |                                             | 3) Striving for innovation (10); | 3) Use of emotion (4);    |
|                             |                                             |                       | 4) Regulation of emotion (4). | 4) The feeling of each section (4). |
| Reliability                 | Correlation of instructors’ scores :       | Cronbach’s α:         | Cronbach’s α:          |                                 |
|                             | $r_{12} = 0.823, p < 0.01;$               | 1) Total: .88;        | 1) Total: .86;         |                                 |
|                             | $r_{23} = 0.853, p < 0.01;$               | 2) Dimension: .69–.79 | 2) Dimension: .72–.87  |                                 |
|                             | $r_{34} = 0.713, p < 0.01);$              |                       |                        |                                 |

TABLE 2. Test items of design innovation and computational thinking.

| Dimensions                  | Items                                                                                              |
|------------------------------|----------------------------------------------------------------------------------------------------|
| Innovation design            | 1) Creativity, such as new ideas, concepts, tools, algorithms.                                     |
|                             | 2) Valuableness, such as reducing cost, promoting performance, enhancing reliability.              |
|                             | 3) Simplification skill: to formulate the task into a design optimization problem.                 |
| Computational thinking       | 4) Embedding skill: to introduce creative ideas into product design.                                |
|                             | 5) Simulation skill: to analyze product performance through discipline theory or simulation tool. |
|                             | 6) Transformation skill: to convert the design option into feasible and valuable engineering design.|

criteria for encouraging students to review the design innovation skills learned.

The questionnaire consisted of the Personnel innovation proaction Scale (PIPS), the Wong and Law Emotional Intelligence Scale (WLEIS), and self-reflection. PIPS contains 22 items (see Appendix A), and defines the connotation of the concept of innovation proaction from three dimensions: desire, preparation, and striving for innovation [17]. WLEIS is a self-report scale (see Appendix B) developed by Wong and Law (2004) based on 418 undergraduates in Hong Kong of China [44]. The validation of WLEIS was investigated through various regional examinations. Overall results
provided evidence that the WLEIS might be a promising tool for assessing emotional intelligence [45], [46]. The self-reflection questionnaire (see Table 3) was used to observe the participants’ perspective on the instruction program, including two dimensions of overall feeling and feeling of four teaching sections.

**D. PROCEDURES**

This study aimed to check whether the IMSP instruction program would improve the participants’ computational thinking and design capability, especially when providing a conceptualization of product sustainability. Another purpose of this study was to check the interaction effects between participants’ personal characters with the instruction treatment. We designed an experimental study to achieve the purposes of this study. The fidelity of the instruction method should include indices of procedure design, instructors, learning materials, instruction receipt, and instruction strategy [47]. These indices were included in this experimental study to ensure its fidelity.

A two-week design practicum was arranged to carry out this experimental study. All data were collected in an online questionnaire survey platform by the instructors. Before the task improvement, the instructors delivered the task statement described in Section III.B to participants for the background reading. Firstly, a four-hour lecture was used as an explanation of the design task, which covered 1) the description of the self-balance vehicle design task, 2) the demonstration of modeling software operational flowchart through an example [48], 3) the presentation about computational thinking. Secondly, they took the pretests, including the SPIP, WLEIS, and design plan report of the self-balance vehicle. Thirdly, the participants received the IMSP instruction program with 13.5 days. Finally, they took the posttest of the design summary report and a self-reflection questionnaire.

We employed the pretest and posttest to evaluate students’ promotion in computational thinking and design capability. The self-reflection questionnaires consisting of 6 items (see Table 3) were adopted to collect the participants’ perspectives on the ISMP program. The procedure of the experiment is shown as Figure 3.

The same IMSP instruction was delivered to the control and experimental groups. The difference was the experimental group arranged a discussion before the IMSP program on the indicators of sustainability, including energy, environment, technology, and economy [12]. After a brief instruction of the indicators, we organized the discussion to guide students to embed the indicators of sustainability into the self-balance vehicle design. The discussion revolved around three issues: 1) which sustainability indicators are relevant to the product design of self-balancing vehicle? 2) how to create a metric model for these indicators? 3) how to embed these indicators into the optimization solution?

| TABLE 3. Items of self-reflection questionnaire. |
|-----------------------------------------------|
| **Dimensions** | **Items** |
| Overall feeling | 1) Importance: innovation design training is important. |
| | 2) Interesting: the IMSP program should be extended to other engineering courses. |
| | 3) Identification: the instruction of the identification section contributed to my task implementation. |
| The feeling of each section | 4) Modeling: the instruction of the modeling section contributed to my task implementation. |
| | 5) Simulation: the instruction of the simulation section contributed to my task implementation. |
| | 6) Prototyping: the instruction of the prototyping section contributed to my task implementation. |

**FIGURE 3.** The procedure of the experimental study.
The design plan report and design summary report submitted by each student were the basis for the pretest and posttest. The design plan report must be submitted after the lecture of the task explanation, and its contents should include design ideas, innovative concepts, technical routes, and expected results. The design summary reports were collected from all the participants at the end of the IMSP program for the posttest, which should at least contain problem identification, modeling process, optimization solution, performance verification. To reduce subjectivity, each report was assigned to three instructors to score, and the average value was recorded as the final score. The two tests were performed blindly from individual and group identification.

IV. RESULTS
A. GENERAL ANALYSIS
The researchers employed SPSS 21.0 for the data analysis in this study. In the pretest and posttest, the three instructors gave their own scores to each design report. Through the Pearson correlation analysis, the pretest scores of the three instructors on the design plan reports were significantly correlated to each other ($r_{12} = 0.82, p < 0.01; r_{13} = 0.85, p < 0.01; r_{23} = 0.71, p < 0.01$), and the same went for the posttest ($r_{12} = 0.74, p < 0.01; r_{13} = 0.81, p < 0.01; r_{23} = 0.69, p < 0.01$). These results showed the reliability of the two tests.

Nineteen participants experienced innovation-related training. Spearman correlation analysis showed that this experience had neither correlation with the scores of the two tests (Pretest: $r = 0.06, p = 0.62$; Posttest: $r = 0.13, p = 0.26$), nor correlation with the evaluations of emotional intelligence ($r = 0.06, p = 0.63$) and innovation proaction ($r = 0.14, p = 0.22$).

Also, we assessed the correlation between the test scores in computational thinking and design innovation through the Pearson correlation analysis. The results showed that there was a positive correlation between the scores of computational thinking and design innovation in the two tests. The correlation of the posttest scores was stronger than that of the pretest scores (Pretest: $r = 0.56, p < 0.01$ vs. Posttest: $r = 0.70, p < 0.01$).

B. TEACHING EFFECTS OF THE IMSP PROGRAM
This study used the scores of pretest and posttest to measure the participants’ performance in design innovation. Using Repeated Measure ANOVA of the grouping variable (Control vs. Experimental), we examined whether there were group differences in the two dimensions of design innovation (DI) and computational thinking (CT), as well as the test items in each dimension. As Table 2, the first and second items were used to measure the performance of students’ performance of design innovation (creativity, valuableness); the third to sixth items were used to measure students’ computational thinking skills (simplification, embedding, transformation, and simulation) when performing the self-balance vehicle design.

1) DIFFERENCES BETWEEN THE INSTRUCTION GROUPS IN THE DIMENSIONS OF DI AND CT
Analysis of the simple main effect (SME) for the grouping variable showed that a group differences in the promotion (pretest vs. posttest) in the two dimensions were significant (DI: $F = 22.46, p < 0.01, R^2 = 0.22$; CT: $F = 22.49, p < 0.01, R^2 = 0.22$). The promotion of the experimental group was higher than that of the control group in the two dimensions. Figure 4 depicts the means and standard errors (SEs) of design innovation and computational thinking for the two instruction groups in the pretest and posttest.

2) DIFFERENCES BETWEEN THE INSTRUCTION GROUPS IN THE TWO ITEMS OF DESIGN INNOVATION
The SME analysis for the grouping variable showed that there was the group difference in the promotion of valuableness ($F = 22.74, p < 0.01, R^2 = 0.23$). The promotion of the experimental group was higher than that of the control group in the test item of valuableness. Figure 5 depicts the means and SEs of the item scores in design innovation for the two instruction groups.

3) DIFFERENCES BETWEEN THE INSTRUCTION GROUPS IN THE FOUR ITEMS OF COMPUTATIONAL THINKING
The SME analyse for the grouping variable showed that there were the group differences on the promotion of embedding ($F = 10.55, p < 0.01, R^2 = 0.12$), simulation ($F = 5.14, p = 0.03, R^2 = 0.06$) and transformation ($F = 17.94, p < 0.01, R^2 = 0.18$). The promotion of the experimental group was greater than that of the control group in the three test items. Figure 6 depicts the means and SEs of the item scores in computational thinking for the control and experimental groups.
The posttest scores were used to check whether there were interaction effects between personal character (Low-level vs. High-level) and instruction treatment (Control vs. Experimental) on participants’ promotions in computational thinking and design innovation. The grouping variables of personal characters included emotional intelligence (EI) and innovation proaction (IP). Each variable was divided at the midpoint into two groups (Low-level vs. High-level) according to the evaluation of EI and IP. Figure 7 and 8 illustrate the means and SEs of promotions in the items of computational thinking and design innovation for the grouping variables of personal character.

1) INTERACTION EFFECTS BETWEEN EMOTIONAL INTELLIGENCE AND INSTRUCTION APPROACH
In terms of design innovation, the results of Repeated Measure ANOVA showed that the interaction effect of participant’s EI-level and instruction treatment was not significant ($F = 1.88, p = 0.17, R^2 = 0.47$). The SME analysis of the EI-level grouping variable showed that it was significant for the experimental group ($F = 7.29, p = 0.01, R^2 = 0.16$), while not significant for the control group ($F = 1.42, p = 0.24, R^2 = 0.04$).

In terms of computational thinking, the findings suggested that the interaction effect of participant’s EI-level and instruction grouping was significant ($F = 4.81, p = 0.03, R^2 = 0.58$). The SME analysis of the EI-level grouping variable showed that it was significant for the experimental group ($F = 18.79, p < 0.01, R^2 = 0.33$), while not significant for the control group ($F = 3.13, p = 0.08, R^2 = 0.08$). The results supported that the high-EI-level group presented greater promotion than the low-EI-level group in computational thinking for the experimental group ($F = 6.18, p = 0.02, R^2 = 0.14$).

2) INTERACTION EFFECTS BETWEEN INNOVATION PROACTION AND INSTRUCTION APPROACH
In terms of design innovation, the results showed that the interaction effect of participant’s IP-level and instruction treatment was not significant ($F = 1.78, p = 0.19$,
The SME analyses of the IP-level grouping variable showed that it was significant for the control and experimental groups (Control: $F = 7.61, p = 0.01, R^2 = 0.17$; Experimental: $F = 15.38, p = 0.01, R^2 = 0.29$).

The results supported that the high-IP-level group presented greater promotion than the low-IP-level group in computational thinking for the control group ($F = 6.78, p = 0.01, R^2 = 0.15$).

In terms of computational thinking, the results showed that the interaction effect of participants’ IP-level and instruction treatment was significant ($F = 5.69, p = 0.02, R^2 = 0.55$). The SME analyse of the IP-level grouping variable showed that it was significant for the experimental group ($F = 16.52, p < 0.01, R^2 = 0.30$), while not significant for the control group ($F = 1.30, p = 0.26, R^2 = 0.03$). The results supported that the high-IP-level group presented greater promotion than the low-IP-level group in computational thinking for the experimental groups ($F = 7.50, p = 0.01, R^2 = 0.17$).

D. STUDENTS’ PERSPECTIVE BASED ON SELF-REFLECTION FOR THE INSTRUCTION PROGRAM

The self-reflection questionnaire was employed to analyze students’ perspectives on the ISMP program. As listed in Table 3, the first and second items reflected the students’ overall perspective, and the third to sixth items reflected students’ perspective on the four teaching sections (Identification, Modeling, Simulation, and Prototyping). Using Repeated Measure ANOVA of the instruction groups (Control vs. Experimental), we examined whether there were group differences in the six test items.

The results demonstrated that the participants in the two instruction groups were positive perspective towards the six items. Figure 9 depicts the means and SEs of the item scores in the self-reflection questionnaire of two groups. The mean scores of the six items were in the interval of [4.2, 4.8]. Moreover, there was no significant difference between the control and experimental groups in each item.

V. DISCUSSION

The purpose of this study was to enhance engineering undergraduates’ design innovation capability through the ISMP (Identification, Modeling, Simulation, Prototyping) program. The application of design innovation and computational thinking was incorporated. Besides, the study investigated the interaction effects between personal character and instruction treatment for the design innovation learning. The researchers proposed six specific hypotheses, which were supported by the results.

A. EFFECTIVENESS OF THE ISMP PROGRAM

The literature supported the significance of embedding computational thinking training into engineering education and developing practical methods for innovation capability enhancement, which is different from the conventional strategies of structured design framework [5]–[7]. This article explored the ISMP program for promoting students’ design innovation capability. The proposed program conformed to the principles and indices of fidelity [47]. Notably, this instruction program embedded the cognitive heuristics of computational thinking skills, including simplification, embedding, transformation, and simulation. The general analysis of the experimental results shows that there was a significant correlation between computational thinking and design innovation, which provided an essential empirical basis for further study of the effectiveness of the proposed program.

According to the theory of constructivism, guided discovery instruction is an effective method for improving conceptual understanding of disciplinary principles. The process of discovery learning is similar to the acquisition of scientific knowledge in the real world, where students go through the stages of hypothesis, planning, experiment, and evaluation [36]. The proposed ISMP program can be viewed as a guided discovery instruction process, in which the applications of computational thinking and design innovation was incorporated. In this study, the conceptualization of product sustainability was applied as an additional experimental condition based on the ISMP program. We hypothesized that the participants would promote computational thinking and design innovation after the ISMP program, with the participants experiencing conceptualization of sustainability outperforming those not experiencing that. The ANOVA results support this hypothesis. All the participants promoted the computational thinking skills after the ISMP program, and the experimental group improved more significantly in the facets of creativity embedding, computer-based simulation, and engineering transformation than the control group. It supports that embedding cognitive heuristics into product design experience would foster design innovation capability [49].

The literature suggested the demand for product sustainability valubleness significantly promoted organized innovation [1]. The findings indicated that the experimental group exhibited a higher promotion than the control group in the
TABLE 4. Personnel innovation proaction Scale (PIPS).

| Dimensions               | Items                                                                                                                                 |
|--------------------------|----------------------------------------------------------------------------------------------------------------------------------------|
| Desire for innovation    | I can keenly identify problems that need improvement in my work.                                                                       |
|                         | I can proactively make suggestions to solve problems.                                                                                    |
|                         | I have a strong interest in innovation and look forward to innovation from my heart.                                                      |
|                         | I have firm determination, perseverance, and goals before innovating.                                                                      |
|                         | I can proactively seek out creative ideas to improve workflow or products.                                                                |
|                         | I am good at listening to others’ suggestions during innovating.                                                                         |
|                         | I can embrace the collisions of different ideas.                                                                                         |
| Preparation for innovation | I believe that others' suggestions always have value.                                                                                 |
|                         | I can find relevant resources (e.g., technology, capital, personnel, information) before innovating.                                      |
|                         | I can search for similar examples before innovating and explore reasons for their success or failure.                                    |
|                         | I can anticipate the challenges that may be encountered during innovation, and presuppose solutions.                                     |
|                         | I can analyze the feasibility of various solutions before innovating.                                                                     |
|                         | I dare to take risks on innovation.                                                                                                      |
|                         | I'm not afraid of failures caused by innovation.                                                                                         |
|                         | I can take the responsibility for failure caused by innovation.                                                                           |
|                         | I can try my best to overcome the difficulties encountered during innovating.                                                             |
|                         | I dare to face difficulties.                                                                                                             |
|                         | I always find a way to solve difficulties, never evade them.                                                                             |
| Striving for innovation  | I can patiently experiment again and again.                                                                                             |
|                         | I am willing to try multiple solutions.                                                                                                  |
|                         | I will never give up easily after repeated failures.                                                                                     |
|                         | I firmly believe that the goal will be achieved during innovation.                                                                        |

Valuableness item of design innovation. The group difference in design innovation supports the hypothesis that understanding and agreeing with the sustainability indicators may lead to the improvement of design valuableness, further promote product sustainability. It supports the literature suggesting the significance of sustainability education on design capability, and that conceptualization of product sustainability can inspire design innovation [12], [15], [30].

The teaching material employed in the IMSP program was a self-balance vehicle design task, where participants practiced the principles and skills of design innovation. The results suggest that modeling and simulation are useful tools for the engineering application of conceptions acquired in the design-based instruction program. These findings support the suggestions that modeling and simulation improved design capability in engineering students [9], [10]. The guidance of modeling and simulation drove students to explore the operation skills of computer-aided engineering software for the real design task. It offered the practical opportunity to apply the computational thinking skills of simplification, embedding, transformation, and simulation. The guided discovery instruction was employed to guide the design skills and elicit learning interest. After the IMSP instruction, the two groups promoted in computational thinking, with the experimental group outperforming the control group. And the differences were significant statistically, which supports the conclusion that computational thinking skills can be improved with training [4], [24].

Besides, to investigate the participants’ perspective towards the IMSP program, we applied the self-reflection questionnaires. The findings reveal that the all participants were strongly positive towards the contribution on their promotion of computational thinking and design innovation during the implementation of the self-balance vehicle design. In summary, computational thinking is the cognitive basis of innovation enhancement, and the proposed IMSP program is a practical way of promoting innovation understanding and design capability. Previous researches on innovation capability promotion few introduce computational thinking training, while this study reveals the possibility of embedding computational thinking in innovation capability cultivation. Moreover, the outperforming performance of the experimental group demonstrates that the conceptualization of product sustainability has potential benefits for promoting innovation valuableness.

B. INTERACTION BETWEEN PARTICIPANTS’ PERSONAL CHARACTERS WITH INSTRUCTION TREATMENT

The literature suggested personal characters are critical factors for innovation capability [16], [18], [37]. In this study, we explored how the personal characters of emotional
TABLE 5. Wong and law emotional intelligence scale (WLEIS).

| Dimensions          | Items                                                                 |
|---------------------|-----------------------------------------------------------------------|
| Self emotion appraisal | I have a good sense of why I have certain feelings most of the time. |
|                     | I have a good understanding of my own emotions.                       |
|                     | I understand what I feel.                                             |
|                     | I always know whether or not I am happy.                              |
| Others’ emotion appraisal | I always know my friends’ emotions from their behavior.             |
|                     | I am a good observer of others’ emotions.                            |
|                     | I am sensitive to the feelings and emotions of others.               |
|                     | I have good understanding of the emotions of people around me.     |
|                     | I always set goals for myself and then try my best to achieve them.|
| Use of emotion      | I always tell myself I am a competent person.                         |
|                     | I am a self-motivated person.                                         |
|                     | I would always encourage myself to try my best.                      |
|                     | I am able to control my temper and handle difficulties rationally.   |
| Regulation of emotion | I am quite capable of controlling my own emotions.                    |
|                     | I can always calm down quickly when I am very angry.                 |
|                     | I have good control of my own emotions.                              |

intelligence (EI) and innovation proaction (IP) interact with the instruction treatment. The results indicate that emotional intelligence and innovation proaction exhibit moderating effects for design innovation learning during the ISMP program. The participants with higher-level of EI and IP outperformed in the promotion of design innovation.

The findings of this experimental study support that emotion may affect the learning of design skills and cognitive ability, which is consistent with the conclusion of previous behavioral researches [41]–[43]. Individuals with high-level EI often experience emotional awakening, which would help their cognitive arousal in design innovation, such as creativity generation, emotional regulation, strategy management, and collaboration [18], [19].

On the other hand, it has been suggested that positive emotion enhances inclusiveness for diversity and flexibility in implementation [17]. The findings indicate that the IP as a type of intrinsic motivation in innovation practice may facilitate computational thinking and awareness of innovation, and provoke autonomous learning [38], [39]. This study suggests that high-level IP also improve individual innovation performance when engaged in product design.

Innovation practice involves conscious and unconscious cognitive processes, and cognitive stimulation could lead to a modulation of bottom-up attention enabling individuals to produce creative ideas [50]. The results of this study indicate that the EI and IP of participants may interact with the IMSP instruction treatment, and then consciously and unconsciously influence the innovation performance in the self-balance vehicle design task. It agrees with the previous studies suggesting that personal characters play an indirect role in promoting design innovation [37], [41].

VI. CONCLUSION
The educational community is exploring the pedagogies of innovation capability with applying advanced design theories and technologies into engineering education. Previous researches on design innovation enhancement mainly focused on professional design skills, such as the structured design framework. This study proposes an instruction method of IMSP (Identification, Modeling, Simulation, Prototyping) for design innovation enhancement with integrating conceptualization of sustainability. Notably, computational thinking training is embedded in the proposed instruction program for inspiring creative ideas and assessing design valuableness.

The design innovation performance is evaluated by the actual product design task of self-balance vehicle. It contributes to the development of design innovation pedagogy in engineering education.

In this experimental study, the main findings are as follows. Firstly, there exists a significant correlation between computational thinking and design innovation, which provided an essential empirical basis for further investigating the effectiveness of the proposed IMSP program. Secondly, the IMSP program promotes engineering undergraduate computational thinking and design capability consciously and unconsciously, and integrating the conceptualization of product sustainability may be a useful strategy for enhancing the learning effects of the IMSP program. Thirdly, the personal characters of emotional intelligence and innovation proaction play a moderating role during the IMSP program, and high-level emotional intelligence and innovation proaction may facilitate design innovation capability enhancement in engineering education. Finally, all participants are strongly positive towards the contribution on their promotion of design
innovation performance during the implementation of the self-balance vehicle design.

Our future research direction is to apply the proposed IMSP program to non-mechanical engineering students, such as civil engineering, electrical engineering. Another important consideration is to introduce artistic elements into the engineering courses to promote students’ diversity and interdisciplinary thinking, further cultivate their sustainability competency from another dimension.

APPENDIX A
See Table 4.

APPENDIX B
See Table 5.

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