Design Science

Framework for a problem-solving educational program integrating medicine and design disciplines at a Japanese university

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Abstract

The design provides innovative solutions to problems in the medical field. Collaboration between design and medicine can be fostered in several ways; however, educational programs linking these two academic fields are limited, and their frameworks and effectiveness are unknown. Hence, we launched an educational project to address medical problems through design. The framework and creative outcomes are based on the results of two consecutive one-year programs. The research subjects were 35 participants from three departments. The majority (22/35, 63%) were master's and doctoral students in design. Eight participants were doctoral students and researchers who volunteered from the surgery, oral surgery, neurology and nursing departments at the Graduate School of Medicine and Hospital. The impact of the program on creativity was evaluated by the quality of ideas and the participants' assessments. In total, 424 problems were identified and 387 ideas were created. Nine prototypes with mock-ups and functional models of products, games or service designs were created and positively evaluated for novelty, workability and relevance. Participants benefitted from the collaboration and gained new perspectives. Career expectations increased after the class, whereas motivation and skills remained high. A framework for a continuing educational program was suggested.

Keywords: Problem-based learning, Medicine, Design thinking, Hospital, Creativity

Received 09 July 2023
Revised 12 December 2024
Accepted 17 December 2024

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Des. Sci., vol. 11, e3
journals.cambridge.org/dsj
DOI: 10.1017/dsj.2024.50

Introduction

Design can deliver innovative solutions to issues in the medical field, including increased patient experiences, clinical outcomes, reduced staff work hours and cost savings (Altman, Huang and Breland, 2018; Lamé *et al.*, 2023). Design thinking (Brown, 2008), a systematic method of the designers' thinking processes, has been applied to develop medical devices (Carroll and Richardson, 2016; Hou *et al.*, 2020) and hospital management systems (Chanpuypetch and Kritchanchai, 2020). In the Netherlands, there is a university medical center where design thinking is being applied to the development of new care models in all departments (Edelman *et al.*, 2017).

Since 2009, design education for medical students, healthcare professionals, patients and educational development has been reported (Cahn *et al.*, 2016; McLaughlin *et al.*, 2019; Ferreira, Savoy and Markey, 2020; Madson, 2021). A well-known

https://doi.org/10.1017/dsj.2024.50 Published online by Cambridge University Press

example is the Biodesign Project by Stanford University, which provides design education to graduate students and fellows focusing on biomedical engineering and entrepreneurial aspirations. Over the past 20 years, it has achieved great success in medical device development, entrepreneurship and fundraising (Augustin *et al*., 2020). Furthermore, in 2019, a qualitative review of design thinking in health professions education reported 15 programs and described a wide range of effects of using design thinking, including fostering self-efficacy and confidence and participant experiences and providing solutions to specific problems (McLaughlin *et al*., 2019). In the Netherlands, a one-semester course called Haking Healthcare was created for medical and art students from multiple universities, as well as participants from interdisciplinary fields such as psychology and neuroscience (Van De Grift and Kroeze, 2016). Participants used design thinking to generate a variety of unconventional ideas for patient-centered healthcare, suggesting the positive impact of this type of interdisciplinary design thinking education on medical education. Students and staff from fields of medicine and design participating in educational programs are expected to improve their minds, motivation and skills related to creativity by experiencing and discussing medical field problems and proposing and testing solutions. Moreover, the ideas generated for clinical problems are expected to produce tangible outputs leading to practical solutions. However, there are limited numbers of reports on on-campus education bringing together students and faculty from the fields of medicine and design. Moreover, the evaluation of the creativity of the ideas generated and the educational effects on participants remain unclear. In addition, many previous studies are based on educational programs in a single medical sub-specialty, and knowledge is limited regarding the framework and effectiveness across various disciplines within medical and design fields in a single university. Especially in Japan, only a limited number of universities have both medical and design faculty, and there are few examples of such programs in university education. Therefore, this study focused on examining how educational programs linking the various sub-fields of medicine and design at university institutions can be implemented and what outcomes they produce.

Aim

In this study, we analyzed the results of an educational program implemented at Kyushu University, in which graduate students who had acquired practical skills in problem-finding and idea proposal to a certain level collaborated with medical staff at the same university to realize and solve problems in various fields of medicine. In this article, we clarify the creativity of ideas generated during consecutive two one-year programs and examine the influence of motivation and skills on the participants' creativity. Finally, based on this experience, we propose a framework for an educational program that integrates medicine and design within one university.

Significance

The significance of this study derived from an educational program in collaboration with both the medicine and design faculty at a single university in Japan is as follows:

- We identified the impact of this program on creativity based on the quality of ideas and participant evaluations.

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- We proposed a framework for implementing a problem-solving educational program that links a wide range of sub-disciplines in both medicine and design at one university.

Literature review

Design is recognized as an interdisciplinary method in both academia and practice (Papalambros, 2015; Ryu and Kim, 2022; Ruiz and Wever, 2024). McLaughlin et al. qualitatively reviewed (McLaughlin *et al.*, 2019) 15 reports on education programs for medical professionals using design thinking, some of which involved collaborations with various professions such as nurses, technicians as well as physicians. However, the majority of the education programs reported here were on a single medical specialty or theme, with limited ones provided on multiple medical specialties. Regarding practical education using design-based methods in various medical fields, the Biodesign project initiated by Stanford University has achieved considerable results in the development of medical devices, entrepreneurship and fundraising over the past 20 years (Augustin *et al.*, 2020). Educational programs linking medicine and design can educate students who do not necessarily aspire to become entrepreneurs. However, especially in Japan, only a limited number of universities have both a medicine and a design faculty, and there are few examples of such programs in university education.

This study focused on what outcomes an educational program integrating various fields of medicine and design at a university institution could produce. In both design education and medical education contexts, the educational benefits of design thinking are associated with creativity and innovation (Sauder and Jin, 2016; Madson, 2021). Creativity is also evaluated in various contexts and is recognized in engineering design for its novelty and appropriateness (Miller *et al.*, 2021). Dean et al. (Dean *et al.*, 2006) surveyed 90 studies on creativity and identified its four main components: novelty, workability, relevance and specificity. Specificity was the least used component, appearing in only 10% of the previous studies. Boudier et al. (Boudier *et al.*, 2023) also revealed six types of reasoning related to the evaluation of ideas, including "discovering six a new path" and "searching for other alternatives." Montagna and Cantamessa (Montagna and Cantamessa, 2019) described the relationship between design and innovation based on structuring the conceptual connections between the important and widely accepted literature on innovation management and the literature on engineering design. The main observed trend is "flexibility" – the digitalization of services and physical deliverables and flexible manufacturing systems such as additive manufacturing. Based on a case study of innovative aerospace design, Kroll and Farbman (Kroll and Farbman, 2016) proposed a common conceptual design methodology called "parameter analysis," contributing to the creation of innovative ideas.

Evaluation criteria for design thinking have also been developed. Blizzard et al. (Blizzard *et al.*, 2015) developed an earlier scale comprising five elements of the design thinking mindset: "feedback seekers," "integrative thinking," "optimism," "experimentalism" and "collaboration." They surveyed 6,772 individuals in the USA. college students. Since then, scales measuring design thinking mindset have been developed in the fields of business engineering field (Roth *et al.*, 2020), higher education (Vignoli, Dosi and Balboni, 2023) and teaching (Cai and Yang, 2023). However, in the medical education context, evaluation indicators used are not

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necessarily related to design thinking, but rather self-efficacy, change or expansion of perception and solutions to specific problems (McLaughlin *et al.*, 2019). Design thinking is also said to foster an entrepreneurial spirit, which may influence interest in working in the medical field and career choices (Holm, Reuterswärd and Nyotumba, 2019; Kremel and Wetter-Edman, 2019; Arendt, 2023). Furthermore, a study synthesized three current cross-disciplinary understandings of design thinking in medical education—a cognitive style, a process of creativity and innovation, and an organizational attribute (Madson, 2021).

Methods

This educational program was conducted as an annual project-based lecture course (once a week, 90 minutes × 2 sessions) taught by four faculty members at Kyushu University Faculty of Design and Hospital. Three members, who specialized in design thinking, product design and digital games, belonged to the Faculty of Design. One member, who specialized in telemedicine engineering and design to support collaboration between faculties and participants, was from the university hospital. This lecture was held as one of the design educational programs for students at the Graduate School of Design and the Graduate School of Integrated Frontier Sciences. Among the medical students, we solicited volunteer participants by email and flyers sent to each medical department at the university hospital. At that time, we presented the purpose of the class and what they should prepare for (Figure 1). The objective of the lecture was defined as being "able to create and demonstrate specific solutions to problems in the medical field by understanding the process of problem finding and solution in design." Twenty-two students from the Graduate School of Design and five from the Graduate School of Integrated Frontier Sciences participated in the class, respectively. Eight graduate students (doctoral students) and researchers from the Surgery, Oral Surgery, Neurology and Nursing departments at the Graduate School of Medicine and Hospital joined voluntarily (Table 1). Because the design, medical and other general education departments are located on separate campuses at Kyushu University, a chat communication system for participants and faculty members was established using Slack. Table 2 shows the class schedule workflow designed using the method provided in the review paper by Simon (1970) through the following steps: 1. medical site visit, 2. identifying problems, 3. creating ideas, 4. idea selection, 5. prototype creation and 6. demonstration. In the first semester, medical participants explained problems to their counterparts in the design field during a medical site visit. A workshop was held to identify problems and create ideas using the Kawakita-Jiro (KJ) method (Nakagawa *et al.*, 2015; Shimizu *et al.*, 2021). Subsequently, ideas were created using images, and each group selected an idea and created a prototype. In the second semester, the participants updated, demonstrated and reviewed prototypes. In the final presentation, all participants and faculty members evaluated each idea. The workshops were conducted on-site using sticky notes to identify issues and online using Miro to organize issues and create ideas. All sticky notes and images were recorded. The number of issues and ideas was analyzed by counting the data from sticky notes and images in Miro.

The program was evaluated based on the creativity of ideas generated and educational outcomes (Table 3). To evaluate the creativity of ideas, we used the three most commonly used elements of creativity proposed by Dean et al.

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Figure 1. Flyers were distributed at the university hospital.

(Dean *et al.*, 2006); novelty, workability and relevance. For each element, participants were given a short description, such as "It is a new idea that breaks preconceptions (novelty)," "It is highly feasible (workability)," "It offers a high degree of improvement over existing methods (relevance)" and were asked to rate the idea on a five-point Likert scale from "1: strongly disagree" to "5: strongly agree." Regarding educational outcomes, all four faculty members set items related to the criteria by reviewing the research on design education in general (Blizzard *et al.*, 2015; Dosi, Rosati and Vignoli, 2018; Coleman *et al.*, 2020), design education in the medical

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Table 1. Participant characteristics

Gender		
	Male	15 (43%)
	Female	20 (57%)
Age		
	Under 30	24 (69%)
	30 and older	11 (31%)
Affiliation		
	Graduate school of design	22 (63%)
	Graduate school of medicine and hospital	8 (23%)
	Graduate school of integrated frontier sciences	5 (14%)
Past experiences of participating in the design workshop		
	Experienced	13 (37%)
	Inexperienced	22 (63%)

Table 2. Class schedule

Timing		Contents
Previous year	March	Finalize lecturer and schedule Call for participants from the medical field
1st semester	April	Orientation
	May	Medical site visit Workshop (identifying problems)
	June	Workshop (creating ideas)
	July	Presentation
2nd semester	October	Idea selection
	November	Prototyping
	December January	Demonstration
	February	Presentation

field (Cahn *et al.*, 2016; Roberts *et al.*, 2016; Altman, Huang and Breland, 2018; Dosi, Rosati and Vignoli, 2018; Deitte and Omary, 2019; McLaughlin *et al.*, 2019; Ferreira, Savoy and Markey, 2020; Hou *et al.*, 2020; Madson, 2021) and using design thinking for creativity education (Razzouk and Shute, 2012; Kijima, Yang-Yoshihara and Maekawa, 2021). Finally, 14 items were established and grouped into categories of “creative mindset and motivation,” “skills for creativity” and “expectations for careers linking medicine and design.” During the self-assessment, participants evaluated themselves before and after the lecture using a five-point Likert scale. In addition, we enquired about the benefits and improvements of the educational

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Table 3. Evaluating items and timing

Evaluating items		Timing: Self-assessment	Timing: Assessment by faculty
Creativity of ideas	Novelty, workability and relevance	Post-lecture	Post-lecture
Educational outcomes	Skills for creativity Skills to lead design research in the medical field (problem identification, idea creation and validation)	Pre- and post-lecture	Post-lecture
	Creative mindset and motivation Importance of design Confidence in creativity Career expectations		-

program and solicited comments in an open-ended format in Japanese. Comments were analyzed using inductive thematic analysis (Braun and Clarke, 2006), and the results of the analysis were translated into English. Two authors (K and T) made summary memos performed coding and then discussed and agreed on the theme. In the instructor assessment, two faculty members (A and B raters) evaluated participants after the lecture regarding "skills for creativity." Microsoft Excel 2019 and IBM SPSS® Statistics 28.0.1.0 (142) were used for statistical analysis. The weighted kappa coefficient was used as the agreement between the two raters in the assessment by faculty (Fleiss and Cohen, 1973). In the self-assessment, Cohen's d (Cohen, 1988) was calculated as the amount of effect before and after the lecture using the major items. The Wilcoxon signed-rank test was used for each item of the pre- and post-lecture assessments, with a significance level of 5%. The Ethics Committee of Kyushu University Hospital (No. 22288–00) reviewed and approved the study protocol for the "Design study of an oral examination table for infants and toddlers."

Results

Finding problems and quality of ideas

Medical participants presented the following issues: Nurses have raised the issue of preparation time and services when washing inpatients' hair. Oral surgeons presented issues in pediatric care, such as challenges regarding immobilization during infant care and difficulty in achieving language training at home for pediatric patients. From the general surgery viewpoint, the need to design waiting rooms for patients and quality of life (QoL) issues for patients with intestinal stomas were highlighted. From the neurological perspective, QoL issues for patients with neurological diseases were raised. In total, 424 problems and findings were identified, and 387 ideas were created regarding the six themes (Table 4). Between one and four prototypes were produced for all themes except the general surgery waiting room. Table 5 shows nine prototypes with mock-ups and functional models of products, games or service designs. Six ideas were product-related, and most of them were modeled in three-dimensional computer graphics (3DCG),

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Table 4. Number of problems and ideas

Category	Problem themes	Number of problems and findings	Number of ideas
Nursing	Hair washing	60	44
Oral surgery	Pediatric care	104	130
General surgery	Waiting room	32	47
General surgery	Patients with intestinal stomas	149	69
Neurology	Neurological diseases patients	79	97
	Total	424	387

Table 5. Evaluation of prototypes

		Median (IQR)			
Prototypes (department)	Styles	Novelty	Workability	Relevance	Average
A warm water dispenser for hair washing (nursing)	Product design, mock-up	4 (4–4)	4 (4–5)	4 (4–5)	4.1
A dental chair for infants (oral surgery)	Product design, mock-up	4 (4–5)	3 (3–4)	4 (4–5)	4.0
Speech therapy games for children (oral surgery)	Four working model, service design	4 (3–4)	5 (4–5)	4 (4–5)	4.1
Information design for patients with intestinal stomas (general surgery)	Graphic design, web design	4 (3–4)	5 (5–5)	4 (4–5)	4.3
Information sharing for hospitalized patients (general surgery)	Product design, mock-up	4 (4–4)	4 (4–5)	4 (4–4)	4.1
Make-up therapy product for neurology patients (neurology)	Product design, 3DCG mock-up	4 (3–4)	4 (4–5)	4 (4–5)	4.0
Rehabilitation game for neurology patients (neurology)	Working model	4 (3–4)	4 (4–5)	4 (4–5)	4.0
Wiring support product for hospital beds (neurology)	Product design, mock-up, and functional model	5 (4–5)	4 (4–5)	5 (4–5)	4.3
Writing support product for neurology patients (neurology)	Product design, functional model	5 (4–5)	4 (3–4)	4 (3–4)	4.0
Average		4.0	4.1	4.1	4.1

IQR, Interquartile range; 3DCG, three-dimensional computer graphics.

whereas mock-ups were made with a 3D printer. The product in Figure 2 is made by combining block shapes to organize the wiring for in-hospital patients, and the design employs the materials used in the 3D printer. Two were rehabilitation training games, and a developed working model reflected images according to the

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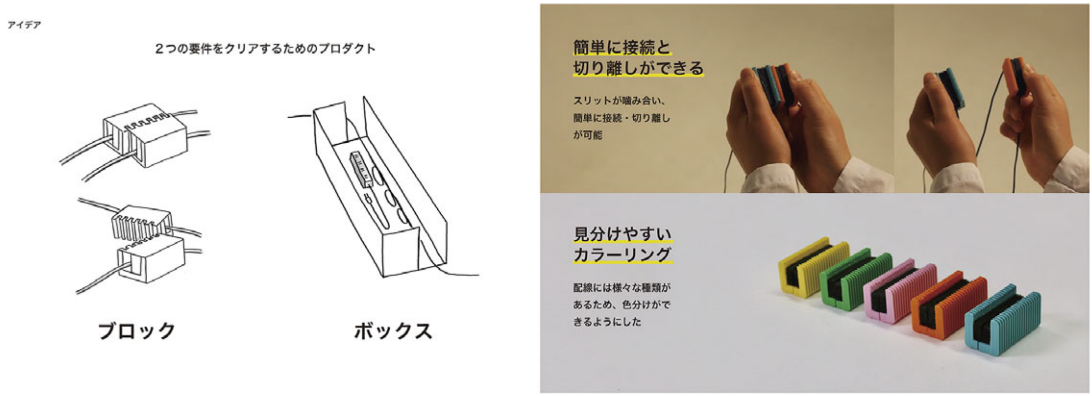

Figure 2. Prototype of a wiring support product for hospital beds.

Figure 3. Prototype of speech therapy games for children.

input of a camera, microphone, and remote controller. Figure 3 shows a mouth training game for children after oral surgery, which uses soap bubbles as an image. The microphone used in the game is modeled after a tool for making soap bubbles and was created with a 3D printer.

The majority of participants rated each idea with a median of 4 for novelty, with the neurology wiring support product and the writing support product receiving a median of 5. For workability, most ideas received a median of 4, with the oral surgery speech therapy game and documentation for patients with intestinal stomas receiving a median of 5 and the oral surgery infant chair product receiving a median of 3. For relevance, the wiring product was highly rated at 5, with the rest receiving a median of 4. Overall, the information design for patients with intestinal stomas and the wiring product were highly rated at 4.3. The values for each indicator were 4.0 for novelty, 4.1 for workability and 4.1 for relevance, respectively (Table 5).

Participant self-assessment

Table 6 shows the self-assessment for each evaluation item. Only the item "Desire for future work related to medicine and design" increased significantly after the class. All four items in the "creativity minds and motivation" category had a median value of 4 or higher in the pre-class assessment, and three items had a maximum value of 5. In the category "skills for creativity," five of the eight items

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Table 6. Self-assessment

Items	Median (IQR) Pre	Median (IQR) Post	P
Creative mindset and motivation			
Want to create something new and innovative	5 (4–5)	5 (4–5)	0.29
Want to improve things that people use everyday	5 (4–5)	5 (5–5)	0.82
Want to design something that will make the world a better place	5 (4–5)	5 (4–5)	0.41
Want to express my original ideas as artwork	4 (3.5–5)	4 (4–5)	0.83
Skills for creativity			
Able to work proactively on problems that do not have clear solutions	4 (4–4)	4 (3.5–4)	0.47
Able to share work with others before it reaches the personal satisfaction level	4 (3.5–5)	4 (4–5)	0.51
Able to take a positive approach without fear of failure	4 (3–5)	4 (3–5)	0.80
Uncover many latent needs and essential problems	4 (3–4)	4 (3–4)	0.32
Uncover users' potential needs and essential problems from unique perspectives	4 (3–4)	4 (3–4)	0.35
Can identify potential needs and essential problems from unique perspectives	3 (3–4)	4 (3–4)	0.57
Able to come up with many ideas	3 (3–4)	4 (3–4)	1.00
Able to express ideas quickly through sketches, models, etc.	3 (2–4)	3 (2–4)	0.78
Expectations for careers linking medicine and design			
Desire for future work related to medicine and design	3 (3–4)	4 (3–4)	0.02*
My participation in this project will be effective for my future career development.	4 (4–5)	4 (4–5)	0.39

IQR, Interquartile range; *P < 0.05

had a median value of 4 in the pre-class assessment. The effect size for each category in the self-assessment was medium to large (d = 0.65) for "expectations for careers linking medicine and design," medium (d = 0.52) for "skills for creativity" and low to medium (d = 0.42) for "creativity minds and motivation."

Assessment by faculty

In the creativity skills assessment by faculty, both A and B raters granted a median score of 4 or higher. In particular, "Able to work proactively on problems that do not have clear solutions," "Able to share work with others before it reaches the personal satisfaction level" and "Able to express ideas quickly through sketches, models, etc" achieved a mean score of 4.5. In contrast, agreement between the two

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Table 7. Assessment by faculty

Items	Median (IQR) Rater A	Rater B	K
Skills for creativity			
Able to work proactively on problems that do not have clear solutions	5 (4–5)	4 (3–5)	0.23
Able to share work with others before it reaches the personal satisfaction level	4 (3–5)	5 (2–5)	0.20
Able to take a positive approach without fear of failure	4 (3–5)	4.5 (2–5)	0.14
Uncover many latent needs and essential problems	4 (4–5)	4 (3–5)	0.20
Uncover users' potential needs and essential problems from unique perspectives	4 (4–5)	4 (3–5)	0.01
Can identify potential needs and essential problems from unique perspectives	4 (3–5)	4 (3–5)	0.26
Able to come up with many ideas	4 (3–5)	4 (2–5)	0.14
Able to express ideas quickly through sketches, models, etc.	4.5 (3–5)	4.5 (2–5)	0.59

IQR, Interquartile range

raters was low for most items (5/8). The lowest was for "Uncover users' potential needs and essential problems from unique perspectives (K = 0.01)" and moderate for the item "Able to express ideas quickly through sketches, models, etc." (K = 0.59) (Table 7).

Thematic analysis

Thematic analysis of the open-ended comments revealed the benefits and improvements of this lecture (Figure 4). The positive aspects of this program were the opportunity to hear from medical professionals and patients (12 comments), gain new perspectives (5), learn comprehensively about creation (3), collaborate with graduate students in other fields to create things (3) and have the outputs evaluated by people in the medical field (2). Participants from the medical field were satisfied with multiple perspectives *(Medical doctor, A)* and learning about the manufacturing process *(Medical doctor, B)*. Design participants stated that working on issues in healthcare while engaging with stakeholders was valuable, useful and rewarding (*Design student, B*).

Improvements included taking more production time outside class hours. This involved improving the time and systems required for the university to procure materials (9 comments), the program structure, such as by involving nurses, medical staff and physicians (6), and communication issues between medical and design participants in hospital access, which was restricted during the COVID-19 pandemic (4). Design participants mentioned that they had to work overtime for a project and wanted to be in charge of more ideas *(Design student, C)* and that they also desired a roadmap to the actual commercialization of the

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Positive Perceptions	Opportunity to hear from medical professionals and patients	"I think it is great that we can identify problems and make design proposals while interacting with stakeholders."
	Gaining new perspectives	"I think it is a good opportunity for the medical side to notice the problems and concerns of patients from a new perspective."
	Learning comprehensively about the creation	"The good thing is to observe matters from multiple angles and have a chance to learn about the actual manufacturing process."
	Collaborate with graduate students in other fields to create things	"I was very excited to be a part of this full-fledged project. I liked the fact that people with different areas of expertise could came together to work on the project."
	The outputs evaluated by professionals in the medical field	"It is not easy to get a chance to collaborate with medical professionals in a hospital and actually get opinions from patients or have them try out the products and services we have created. If you want to have such an experience, I think you should definitely participate in this class."
Negative Perceptions	Improving the time and systems required for the university to procure materials	"There was a lot of overtime work. It was a bit regrettable that the number of projects I could work on was limited to only one." "There is a long lag time before the order arrives."
	Improving the program structure	"I wish there was a pre-made roadmap for actual commercialization."
	Improving communication issues between medical and design participants	"I hope hospital access will go more smoothly after COVID-19 settles down."

Figure 4. Summary of thematic analysis.

product (*Design student, D*). The problem related to the time lag between placing and receiving an order and the ordering system was also mentioned (*Design students, E and F*). A participant from the medical field expressed that access to hospitals was difficult due to the pandemic, and the ease of infection situation would improve access in the future (*Medical doctor, A*).

Discussion

Finding problems and quality of ideas

The collaborative educational project between medicine and design involved four medical disciplines of general surgery, oral surgery, neurology and nursing for a two-year period. As a result, 424 problems were identified, 387 ideas were generated, and nine prototypes were created for product, service and game design mock-ups and working models. In the first year, we conducted the project with three medical departments; however, we were unable to create a prototype for the waiting room theme proposed by the general surgery. One of the reasons for this was a lack of time. Visiting the three departments and holding workshops to identify issues required considerable time in the first semester. Another reason was the theme relevance. The problem of outpatient waiting rooms is not a theme specific to the surgery department, and we needed to investigate other medical departments as well. Therefore, it is important to select themes carefully to identify problems rooted in the medical department and conduct on-site inspections. This is also supported by the number of prototypes. The department with the largest number of prototypes was the neurology department, where interviews were conducted with patients with intractable neurological diseases that limit physical movement, which enabled learning about the various problems they face in their daily lives. This allowed

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participants to identify various problems in daily life related to writing, makeup, hospitalization, outpatient visits, generate concrete ideas, and propose numerous prototypes.

Prototypes received positive feedback, with an average of 4 or higher out of 5 points for relevance, novelty, and workability. There was no difference between medical sub-specialties, but the speech therapy game and graphic design for patients with intestinal stomas were particularly highly rated for workability, likely because most of the production is performed digitally. Although the design of the product is done digitally up to the middle, the final prototype is created analogously; thus, users may get the impression that it is farther from completion than digital content or graphics. However, most proposed prototypes were products, which shows the need for product design in the medical field.

Research on creativity suggests that the process of actually making something enhances creativity, whereas a certain degree of risk is essential (Ross and Groves, 2023). Furthermore, the flexibility of digital production is crucial for innovation (Montagna and Cantamessa, 2019). In this class, we used both digital and analog methods to create prototypes through trial and error, which we believe led to high-quality output. At the final presentation, there was a discussion about the practical application of the prototypes. Unfortunately, no prototypes have been put into practical use yet, but about half of the themes are being pursued as research after classes. Of the ideas, documents for patients with intestinal stomas received the highest overall evaluation; as they are paper-based prototypes to be distributed to patients, the barrier to entry is low. The games and products that directly affect patients require further development and safety evaluation, followed by user feedback and social implementation through industry-academia collaboration. In this regard, support is being sought from an organization in charge of medical device development at university hospitals.

Participant self-assessment

Participants' self-assessments revealed that their career expectations increased, whereas their motivation and skills related to creativity remained unchanged. Regarding motivation, the median value was 5, which was the maximum value before the class, and therefore, motivation remained unchanged after the class. Most participants who chose this course had fairly high motivation for creativity, which remained at the highest level throughout the class. Regarding skills, most items had a median value of 4 before attending class, suggesting that the design graduate students, who comprised the majority of participants, had a certain level of skills. On the other hand, for many participants, this class was the first opportunity to work on a real medical topic. Therefore, participants learned that many problems in healthcare require design, and they were able to experience the effectiveness of design thinking by receiving feedback from experts in the medical field on the ideas they generated. Prior studies have also reported the positive impact of design thinking and creativity on entrepreneurship and careers (Holm, Reuterswärd and Nyotumba, 2019; Kremel and Wetter-Edman, 2019; McLaughlin *et al.*, 2019). Furthermore, design education is positively correlated with students' beliefs about their ability to engage in new product development, whereas expertise in design education affects self-efficacy in entrepreneurship (Christensen *et al.*, 2023). The results of this study also support previous studies,

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but the career impact of this program needs to be analyzed in more detail in the future.

Assessment by faculty

The creativity skill evaluation by the faculty was very high, with a median score of 4 points or more; however, the agreement between the two evaluators was low for most items. This is probably because the five-point Likert scale was used, and the degree of evaluation varies depending on the evaluator. The agreement may be improved by developing and using an evaluation scale such as an analytical rubric that expresses individual criteria in a sentence (Rhodes and Finley, 2013; Campbell *et al.*, 1993). In addition, the agreement was higher for the ability to immediately express ideas in sketches or models than for other items, likely because individual skills are easier to understand and evaluate than ideas and problem identification. Previous studies have employed participants' self-evaluations, but objective evaluations have often not been conducted (McLaughlin *et al.*, 2019). In a class such as this one, which is mainly group work, it may be necessary to use each participant's report in the evaluation to properly evaluate all participants. In addition to faculty evaluation, it may be possible to evaluate each other's growth by having participants who do group work together to evaluate each other objectively.

Thematic analysis

The comments from participants from both medical and design fields indicate that this program provided them with a meaningful and positive experience. The design participants tackled previously inaccessible yet familiar problems in a clinical setting. Specifically, they identified the problems themselves, worked with team members having diverse skills and received feedback and ideas from healthcare professionals. Furthermore, the medical participants proposed solutions to their problems from a new perspective through design, discovered clues to solutions by creating prototypes and experienced manufacturing processes for the first time.

In addition, challenges in conducting the class were also identified. The first is to ensure a means of communication. Design students were reserved in contacting medical professionals involved in clinical work, and time coordination among participants was difficult. The chat tool facilitated the contact during their spare time. However, some aspects of online communication were not satisfactory. Especially in the second semester, obtaining prototyping options became necessary, and faculty members carried the production of ideas to the hospital for opinions because students from other campuses were not allowed to enter the hospital during the COVID-19 pandemic. Therefore, it was difficult to receive evaluations for games and other items that required setup. Online and in-person, on-demand and real-time means of communication need to be prepared according to the purpose. The second point is to make the class content compact and improve efficiency. Most overtime was done by participants immersed in their own creations, but it is necessary to find ways to make class time more compact. KJ method workshops should be conducted with 2–3 groups of 5–6 participants per group because of the time required to put out sticky notes when there are multiple people. In addition, an environment that allows prototyping based on free ideas must be prepared. In this

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class, necessary materials had to be purchased each time, and the lack of immediate prototyping was also an obstacle to rapid fabrication. In their book, Ku and Lupton (Ku and Lupton, 2020) propose a health design lab equipped with a cart full of various prototyping materials such as markers, yarn, aluminum foil and clay, where students can freely prototype 24/7.

Program framework

The framework of this problem-solving educational program collaborating with medicine and design departments at a university is shown in Figure 5. The faculty comprised four members: three from the design faculty and one from the hospital. Design faculty members specialized in services, products, digital content and games could broaden the range of freely generated ideas, and the final prototypes took various forms. On the other hand, the number of medical department members involved in a single class was limited to two, in consideration of the time spent on producing high-quality ideas and prototypes. To produce more substantial outputs in the future, it is necessary to involve faculty members with a variety of expertise in both medicine and design; however, deciding at what process stage they will be involved is also important. Based on past research, having a system in

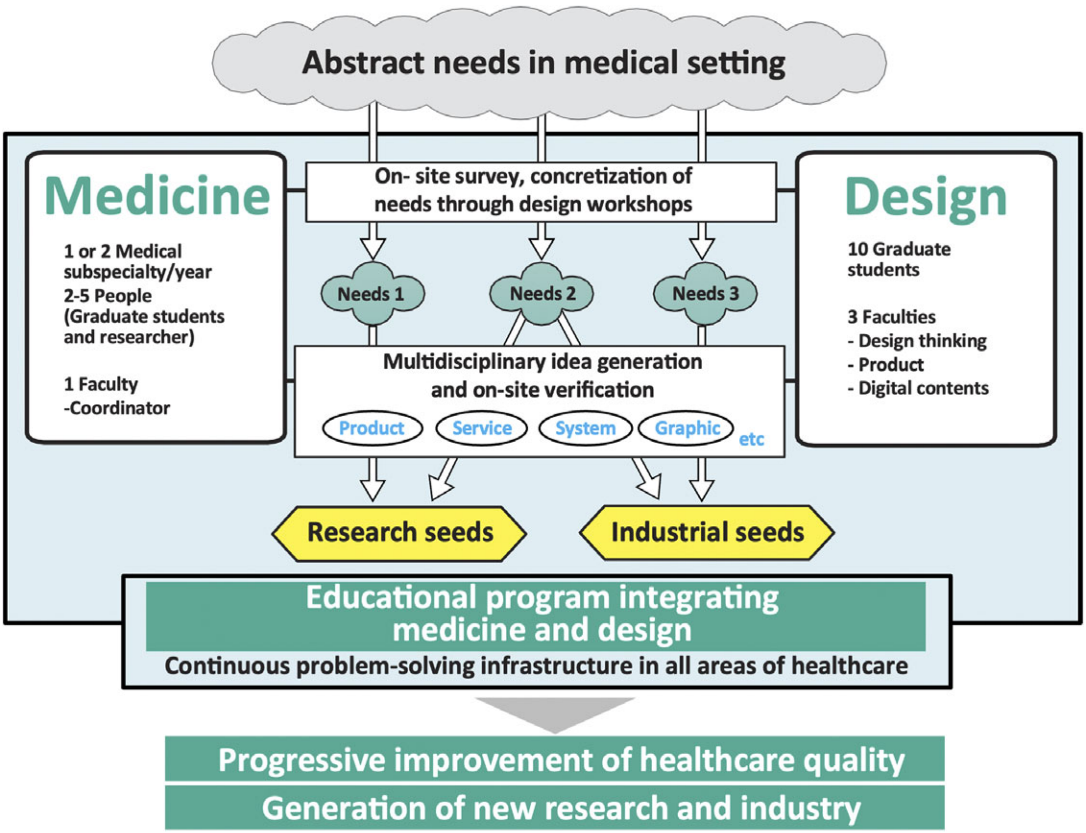

Figure 5. Framework for a problem-solving educational program that integrates the two academic disciplines of medicine and design in a university.

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which design thinking supports the process from problem identification to idea development is desirable. More specialized faculty members provide support during the generation of unique ideas from this process. A faculty member from the hospital was involved in this project as a coordinator because collaborating with participants was essential. With expertise in both medicine and design, this faculty member developed a rapport with participants and faculties from both disciplines to facilitate communication, especially between the medical and design participants, who tended to be reserved toward each other.

Because the participants themselves performed everything from problem discovery to idea identification during the one-year program, the final outputs were prototypes. Some of them are currently studied in collaboration with other laboratories, and further verification and improvement are expected for social implementation in the future. Therefore, a framework is necessary for continued efforts after the class. Collaboration with academic research organizations is also required to promote medical device development (Goldenberg *et al.*, 2011). If such a program is implemented over the long term, it could lead to collaborative research and social implementation between the two fields to efficiently respond to medical challenges. Moreover, it could strengthen connections between people from both faculties and generate related research to improve the quality of medical care in the future. To ensure the sustainability of such a program, it was essential to consider the benefits to the clinical site participants who volunteered. In this program, there were many benefits to the clinical field, such as solving actual problems, extracting issues and developing collaborative research. For example, in the field of neurology, nearly 100 life problems were identified based on interviews with patients. Specifically, this field aims to improve the quality of patients' lives; because observation and extraction of issues using design thinking had not been done before, the extracted issues themselves became the research theme. It was also advantageous that some generated ideas, such as documentation for patients, had low implementation hurdles and research into products in the field of oral surgery has progressed to the point of being proven. This is closely related to the fact that the research team included faculty members specializing in both the medical and design fields. The fact that faculty members from both fields understand the benefits of each field is likely to have a major impact on sustainability.

Limitations and future research

Although this study evaluated creativity in the constructed program, the relationship with design thinking metrics should also be clarified (Blizzard *et al.*, 2015; Dosi, Rosati and Vignoli, 2018; Coleman *et al.*, 2020). Analysis related to group work is also needed as collaborative stimulation in group and individual design thinking has been previously compared (Sauder and Jin, 2016). A study also showed that more influential influencers were involved in decision-making in group design thinking (Singh, Cascini and McComb, 2022). Because the opinions of medical experts are often regarded as important, they may be considered influencers. Future studies should also examine the interdisciplinary group work of participants from the design and medical fields and other fields (Alves *et al.*, 2007; Ferreira, Savoy and Markey, 2020). An analysis is also required for evaluation measures other than design thinking, as studies (Yeager *et al.*, 2016; Deitte and Omary, 2019) have found that design thinking improves the growth mindset, supporting the idea that "one's

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growth can be improved through experience and effort." A growth mindset with design thinking skills is a powerful indicator, and the impact of its integration with design and the medical field should be evaluated. Second, only two-year data were included, which means that the number of participants and output is small, and no comparison was made between those who did and did not participate in this study. A comparative study is required to increase the output. In addition, the agreement of the evaluation criteria was low and lacked intensity. Additional studies should be conducted using the aforementioned indicators. Furthermore, long-term outcomes are unclear, and employment outcomes must be investigated after a few years. Nonetheless, this study identified the framework and outcomes of a problem-solving educational program that collaborated with medical and design fields at a Japanese university with respective students and faculties.

Conclusions

We developed a problem-solving educational program involving collaboration between the medical and design fields at a Japanese university. The results of the two-year program revealed points to consider for creative outcomes in the framework. A total of 424 problems and 387 ideas for oral surgery, general surgery, neurology and nursing were identified. Finally, nine prototypes with mock-ups and functional models of products, games or service designs were created and evaluated highly for their relevance, novelty and workability. Moreover, career expectations increased after the class, whereas motivation and creativity remained high. The framework of the educational program was drawn up, and issues related to the long-term effectiveness and social implementation of the creative outcomes were clarified.

Acknowledgments

The authors are grateful to all participants and faculty members in the medical and design fields who made this course possible.

Funding statements

This work was supported by JSPS KAKENHI Grant Number JP23K17621, JP23H01005 and QR Program 02103.

Disclosure statements

All authors declare no conflict of interest.

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