# Interdisciplinary Education for Design Innovation

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*A design education program must unite traditionally siloed disciplines, spanning rigid academic boundaries from engineering to social sciences. Work to establish the Kyoto University Design School had to meet these challenges in promoting interdisciplinary cooperation and provides a solid model for others to build on.*

Scientific communities across the globe are being pressed to solve an array of daunting problems, such as global warming, disaster mitigation, and energy and food scarcity. These problems exceed the abilities of any one discipline, which means that experts from diverse fields must work together to provide a range of problem-solving perspectives. For example, in determining the cause of a collision, a mechanical engineer might surmise that the vehicle's engine was at fault, a computer scientist might deduce that the vehicle's control system was the main problem, an architect might point to poor urban design as the main contributor, a psychologist might propose that the driver was inattentive, and a management specialist might speculate that the driver suffered from overwork. In this way, problems are attacked with an assortment of strategies for preventing similar scenarios. This collaboration of multiple disciplines also ensures that problem solving moves ahead: if a challenge stymies experts in one discipline, those in other disciplines can continue the work of evolving solutions.

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But interdisciplinary collaboration is not a familiar problem-solving model. In the simple traffic accident example, contributions are likely to converge reasonably into some solution that addresses the multiple concerns: car, driver, city planning, and work conditions. However, on challenging problems faced by society as a whole, experts have widely varying ideas on what the focus should be. These divergent views and interpretations become a serious barrier to interdisciplinary collaboration. Thus, any grand-challenge project must cultivate not only its own expertise in a specific domain, but also broaden its understanding of the issues by examining perspectives on the same challenge in other disciplines.

Design education and research is an emerging mechanism for implementing an interdisciplinary approach. Over the last decade or so, universities have established many specialized design departments, such as mechanical, systems, environmental, and architectural. Kyoto University is attempting to unite these into a design school that links domain-dependent design education and domain-independent design. We are continuing to refine the school on the basis of lessons learned about design's evolving nature and to create a common understanding of vocabularies and curricula for design education. We are already seeing many similar efforts worldwide, and hope that creators of design education and research programs can share their experiences openly.

## WHAT IS DESIGN?

Before we could establish the design school as an interdisciplinary center of study and research, we had to clarify what we meant by "design." We found this definition particularly useful: "a specification of an object, manifested by an agent, intended to accomplish goals, in a particular environment, using a set of primitive components, satisfying a set of requirements, subject to constraints."[1]

### Interpreting the definition

This definition is sufficiently abstract that each domain can easily apply its own interpretation. Computer scientists, for example, are likely to associate this definition with optimization problems. If the design problem's goals, constraints, and requirements can be formally specified, then optimization algorithms and high-performance computing could be applied to the search for solutions. As long as a problem can be formalized, this interpretation works. However, "design" is already shifting its focus to the much more expansive universe of societal systems and architectures made up of organizations and communities. Issues in this context cannot be approached as simple optimization problems. For example, architects often interpret this definition in a more social way. Urban design projects might require convening a stakeholders workshop to determine all the community requirements, which might represent many social concerns. Thus, the project's boundaries become fuzzier. Once a problem moves out of formalization's clear limits, the most suitable computational theory and method for dealing with it are not obvious.

An example is Japan's mission to redesign cities and communities after the 2011 East Japan earthquake brought into sharp focus the need to equip communities and protect them against future natural disasters. The process of problem solving (how to design) inevitably involves the process of problem identification (what to design). Since society can be abstracted at various levels, the models for expressing problems can have many layers. Consequently, the problem-solving process can flow up and down among the model's different layers. For example, a project to improve a city's transportation network entails changes to the existing bus routes, which triggers the additional challenge of gaining residents' consent. This, in turn, requires sharing a vision of the city's design. In this sense, design is not only about solving problems in the here and now, but also about answering questions on how to shape society for the future.

### From making to nurturing

The Science Council of Japan's 2003 proposal for artifact design (with artifact being an abstraction) and production pointed out the need to expand the design process from making products to projects that involve understanding and nurturing relationships and environments.[2] This shift is particularly noticeable in mechanical engineering and architecture, in which the emphasis is moving from the technology per se to designing user experiences. At the same time, in computer science, the traditional concern of how to implement complex logic is giving way to exploration in how to link hardware and software elements to social functions.[3]

## DESIGN STUDIES EVOLUTION

Surprisingly, design began to evolve from the act of identifying and resolving problems as far back as the 1960s. In 1969, Herbert A. Simon, an innovative thinker in economics, decision making, and AI, wrote

> *Most of the complexity of [people's] behavior may be drawn from their environment, from their search for good designs. If I have made my case, then we can conclude that, in large part, the proper study of mankind is the science of design, not only as the professional component of a technical education but as a core discipline for every liberally educated person.* [4]

Just a year later, Tadao Umesao of Kyoto University shared the following view in his "Designers in an Information Industry Society" lecture:

> *The methods of developing substances and materials have tremendously evolved over the years. And, we now have access to all the energy we need. Against this backdrop, our top challenge is the question of design, or how we should combine these methods of development and sources of energy. It seems that designers in this information industry era are, or will become, nexuses of all the essential elements of industry.*[5]

Both men recognized early on that information and design industries would converge—a remarkable insight in an era when universities had just launched large computer centers.

As time passed, design as a social problem-solving industry became hampered by strong global constraints on technology, culture, economy, and politics. These constraints produced dependencies that have grown into complexly intertwined problem networks. Discontinuing the use of nuclear power will likely accelerate fossil-fuel consumption, for example, and increasing bioethanol production will likely cause grain prices to rise. Due to these interlocking constraints, the task of designing society's systems and architectures has ceased being a simple optimization problem and instead has become a control problem dealing with intricately intertwined networks. In this new environment, design studies are uniquely positioned to apply the latest theories of modern science and technology.

## ESTABLISHED DESIGN SCHOOLS

The interdisciplinary nature of design schools makes it difficult to pigeonhole them within the typical university's organizational structure of segmented disciplines. Not only is the design school concept still nascent, but each discipline has established its own design theories and methods. Thus, a design school must be an interdisciplinary institution, yet be fully grounded in many discrete disciplines. There are a range of approaches in implementing this vision. Typically, though, design schools emerge from specific disciplines—computer science, architecture, mechanical engineering, and so on—and then grow toward an interdisciplinary model of education and research.

### Stanford University

The Hasso Plattner Institute of Design, also known as d.school, opened at Stanford University in 2004. Starting from mechanical engineering and computer science, it offers a variety of workshops and courses that emphasize hands-on design practice. Although d.school is neither a graduate school nor an academic department and has no specific student cadre or degree, it is still connected to Stanford's established disciplines. For example, members of the mechanical engineering faculty participate in d.school, and students that want to join its program enroll through that department. Prominent faculty members in d.school also work at IDEO, a design firm that is garnering attention for its efforts to translate design thinking into business,[6] although the two organizations are independent.

### Harvard University

Harvard University's Graduate School of Design, established in 1936, combines architecture, urban planning, and landscape architecture. As such, it has a more confined scope than recently created design schools. Harvard's collaborative master in design engineering is probably a closer fit. The program, jointly developed in 2016 by the Graduate School of Design and the John A. Paulson School of Engineering and Applied Sciences, pursues interdisciplinary education and research with the goal of making design a nexus for technology, society, and the environment.

### Delft University of Technology

The Netherlands' Delft University of Technology's Faculty of Industrial Design Engineering has been a vibrant center of interdisciplinary education and research since its inception in 1969. Led by its own staff of instructors representing disciplines such as psychology, mechanical engineering, and computer science, the school strives to maintain a balance between domain-dependent and domain-independent design while building a design model that combines social desirability, technological feasibility, and commercial viability.

### Aalto University

Finland's Aalto University is an interdisciplinary hub of education and research that was founded in 2010 from merging three universities—one specializing in engineering, one focusing on art, and one emphasizing economics. Aalto's design activities center on healthcare, aging society, global warming, and other areas with grand challenges. Because of its founders' belief that such challenges cannot be solved by universities alone, Aalto strongly emphasizes partnerships with industry.

## SCOPING CURRICULUM

Because of its interdisciplinary nature, a design school cannot rely on traditional curriculum models. Rather, as Figure 1 shows, domain-dependent design theory, method, and practice must combine with the same elements but in a domain-independent context. For example, in computer science, domain-dependent design theory would include computational theory, method courses would include software engineering, and practice would involve programming exercises. Domain-independent design courses would focus on the design of artifacts, information, organization and community, and other societal elements as well as on design methodology—courses that examine the concept, philosophy, and history of design. In this sense, "domain-independent" has two meanings: general and quintessential.

Even if a framework such as that in Figure 1 can be used to systemize curricula, many graduate students will lack the motivation to study design along with their chosen field. Their reasoning might go something like this: I understand that societal problems are complex, but why can't experts from the relevant disciplines become a project team that is tasked to solve them? I'd be better off studying project management, not design, wouldn't I?

The answer to that question is "no" for two reasons. First, research that significantly impacts society is typically produced from a nexus of disciplines. Computer science innovation often occurs at the borders of other disciplines. Google's ad auction, for example, was invented at the border of computer science and economics. Studying design equips students with knowledge and skills that broaden the horizons of their degree research.

Second, studying fields outside a chosen discipline involves more than learning research achievements; it requires understanding the methodologies and processes that enabled them. If, for example, computer scientists and psychologists are going to work together, each group needs to know the research processes that the other uses. Universities can provide an ideal environment for such multidisciplinary learning.

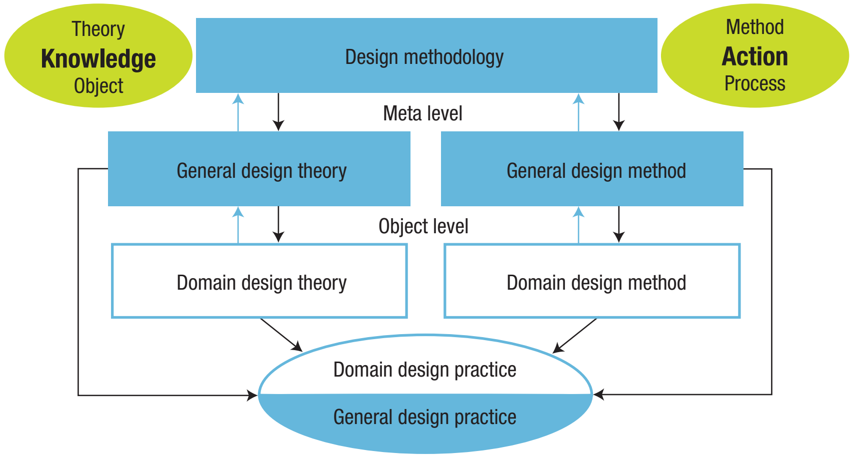


**FIGURE 1.** Framework to characterize a design school curriculum. Traditional domain-dependent courses include design theory, method, and practice (white), which focuses on creating products. These must ultimately merge with domain-independent theory, method, and practice (blue), which is more concerned with design as applied to societal elements and with understanding design as a concept.

## KYOTO UNIVERSITY DESIGN SCHOOL

In April 2013, Kyoto University launched the collaborative graduate program in design, which is more familiarly referred to as the Kyoto University Design School, an integrated five-year doctoral program aimed at cultivating people who can design social systems and architectures through collaboration with experts from diverse fields. The program seeks to nurture students into experts who can bring about changes in society by educating them in design as a lingua franca that unites people across disciplines.

As Figure 2 shows, the program is founded on five disciplines in four graduate schools: informatics, mechanical engineering, architecture, management, and psychology. Informatics, mechanical engineering, and architecture comprise what has become accepted as a design school's core. We included management and psychology to establish the link between technologies and societies. Design applications do not target only these five areas, of course, but address far-reaching challenges in environmental, healthcare, and disaster management, among many others. The Kyoto University Design School's logo is three plus signs, underlining the goal of producing people with "+ shaped" confidence—those in different disciplines who are connected through design education (design.kyoto-u.ac.jp).

### Coursework

The curriculum consists of coursework and PhD research. The coursework comprises general design and domain design courses (major) to be taken in the first half of the program followed by domain design courses (minor) to be taken in the second half. The general design courses include

- design methodology, which discusses what design is;
- general design theory, which explores the basis of interdisciplinary design, including design of artifacts, information, organizations and communities; and
- general design method, which covers field-analysis techniques

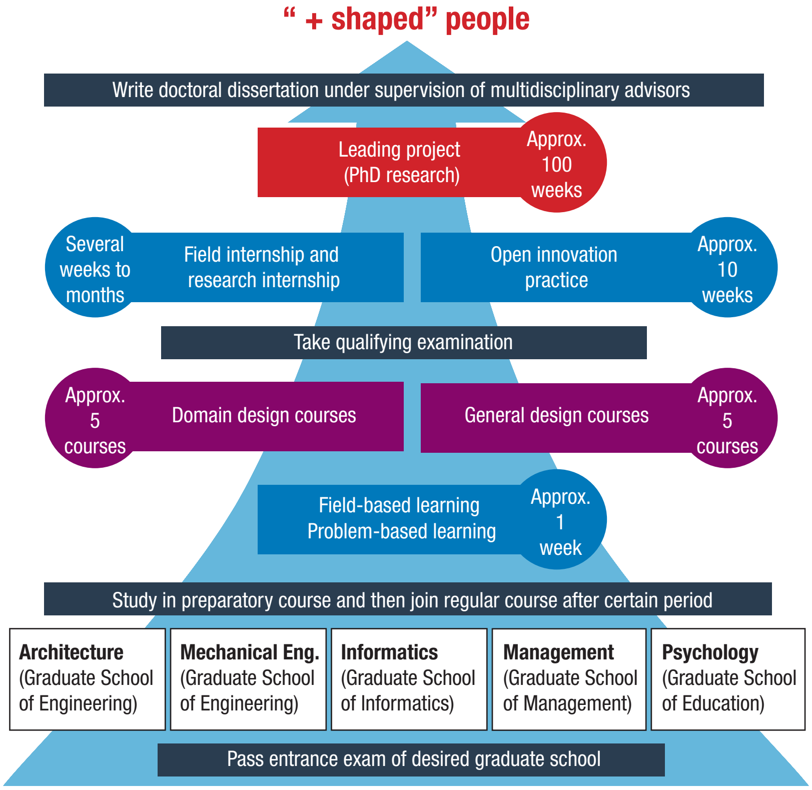


**FIGURE 2.** Kyoto University's collaborative graduate program in design. Five disciplines make up the program's core, but discipline crossovers and extensions are part of the program. Students incorporate design courses (purple) and design practices (blue) into their chosen major. Coursework and projects are augmented with field-based and problem-based learning experiences. As students pass through each academic milestone (black) using design as a lingua franca to connect to those from different disciplines, they move closer to becoming "+ shaped" experts who can work together to change the world.

such as ethnography, data analysis, and simulation as well as methods of composing design and design processes.

The first half of the doctoral studies also includes courses on field-based learning (FBL) to hone skills in identifying real-world problems and problem-based learning (PBL) to discover ways of finding solutions to real-world issues. Most topics are developed from actual problems chosen by faculty members, such as how to expand the use of renewable energy or how to reactivate a shrinking rural area. These challenges give students the full measure of a real problem.

The second half of the doctoral studies consists of courses in which students work on full-scale, hands-on design challenges with experts from other fields. The open innovation practice involves taking on real-world problems posed by business sectors, and elevates students from budding specialists to the role of facilitators who manage teams of domain specialists. The field internship, which brings educational resources to bear on real issues, is the most challenging learning experience. Multidisciplinary student teams travel to locations across Japan or in other countries to work on solving local problems.

These practical applications become more difficult as program participation progresses. Third-year students assigned to a field internship in Indonesia were confident that they could successfully complete the work involved because of the experience they accrued from the program's incrementally challenging hands-on practices.

At the end of the program, students complete interdisciplinary projects and write their dissertation in their own department under the guidance of multidisciplinary advisors.

## Broad-scale design collaboration

In addition to regular courses, the program offers learning experiences in different environments and cultural settings. Immediately after the 2011 East Japan earthquake (and prior to forming its design school), Kyoto University established the Summer Design School, shown in Figure 3, a three-day event that gives students the opportunity to collaborate with participants from other universities, government, and industry. The 2016 Summer Design School featured nearly 30 workshops and had more than 350 participants, including both students and instructors.

One of the event's strongest benefits is that activities are outside the traditional instructor–student dichotomy. Instead, there is nearly a one-to-one ratio of instructors to students. This model promotes mutual learning experiences in which participants collaboratively identify the problems to tackle. Industry provides a third of the workshop topics, adding the dimension of industry–academia crossover to the students' educational experience.

## Design Innovation Consortium

Recognizing the need to work with business and government agencies, universities have established various frameworks for joint research projects, and when everyone understands and agrees on what the project needs, these frameworks serve their purpose. However, most projects require at least some initial exploration, which calls for discussions among the participating experts. Such discussions can sometimes be at odds, yet to guarantee the sustainability of education, universities must pursue collaborative projects. For these projects, which can involve businesses, governmental agencies, and other universities and research institutes, existing joint research frameworks are insufficient. Participants often have different purposes and operations, yet consensus is required to work together effectively on the issues. Rather than having different sides negotiate for every project, Kyoto University decided to form an organization that operates under a comprehensive agreement for collaboration.

The Design Innovation Consortium, launched in March 2014, is tasked with jointly researching the most effective ways to develop needed skills in graduate students (primarily) and company personnel. The consortium, which had approximately 60 corporate members as of March 2017, is a hub for sharing the design theories and methods developed in universities and the real-world challenges faced by industry and government.

Member companies supply fellows—experts strongly motivated to participate in design activities—to work alongside faculty and students in design projects and establish long-term collaborative relationships. Serving as mentors to the students, these fellows offer advice on how to translate university research achievements into forms that serve society. Exposure to the fellows' extensive knowledge and experience helps students to better understand the diverse career paths.

**FIGURE 3.** Collaboration at the Summer Design School. The three-day event, sponsored by the Kyoto University Design School, provides students with the opportunity to experience design collaboration with specialists from university faculties and companies.

## DESIGN SCHOOL EVALUATION

Although the Kyoto University Design School has not yet seen its first-year students reach their fifth year, it is already making an impression on various stakeholders. To measure reactions to the school, we surveyed all third-year students and on the basis of the survey developed a design innovator index.

### Student survey

We distributed a questionnaire to eleven students that covered seven topics: collaboration with people from different fields, project and meeting facilitation, global collaboration, effective communication, effective presentation, design knowledge and methods application, and research focus enlargement.

Of the eleven students surveyed, seven responded that they had developed skills to collaborate with people from other fields and six felt that they had the skills to facilitate projects. Five students thought they had learned how to globally collaborate and effectively communicate and had developed knowledge about design and design methods application. In contrast, seven students thought they still needed to work on making effective presentations and enlarging their research focus, but they were confident that they would have both these skills by the program's end.

Comments like these were typical on the questionnaire: "I learned how tough it is to facilitate and about ways to bridge different opinions" and "I gained the confidence to produce meaningful results in collaboration with people from different cultural backgrounds and areas of expertise by gradually expanding discussion with an open-minded approach." Figure 4's journey maps illustrate two students' paths to find dissertation topics for their PhD research. Students started with interests in relatively narrow research areas, freely used the interdisciplinary opportunities provided as part of the curricula, and settled on themes that were both attractive in their disciplines and connected to social issues.

### Design innovator index

The design innovator index, which assesses learning quality at the Kyoto University Design School, was created from empirical data to identify the skill set that excellent design innovators possess. Figure 5 shows the index and the skill set, which is structured in four areas for a total of 24 competency milestones. The areas, originally defined by the UK's Researcher Development Framework,[7] are regarded as core competencies to be nurtured as transferable skills.

We use the index to assess the students at the beginning of a course, when they take qualifying exams in the third year, and when doctoral work is complete. The ratios in Figure 5 are based on 15 students at admission and 13 students thereafter. Through these assessments, students clearly understand the key knowledge, behaviors,

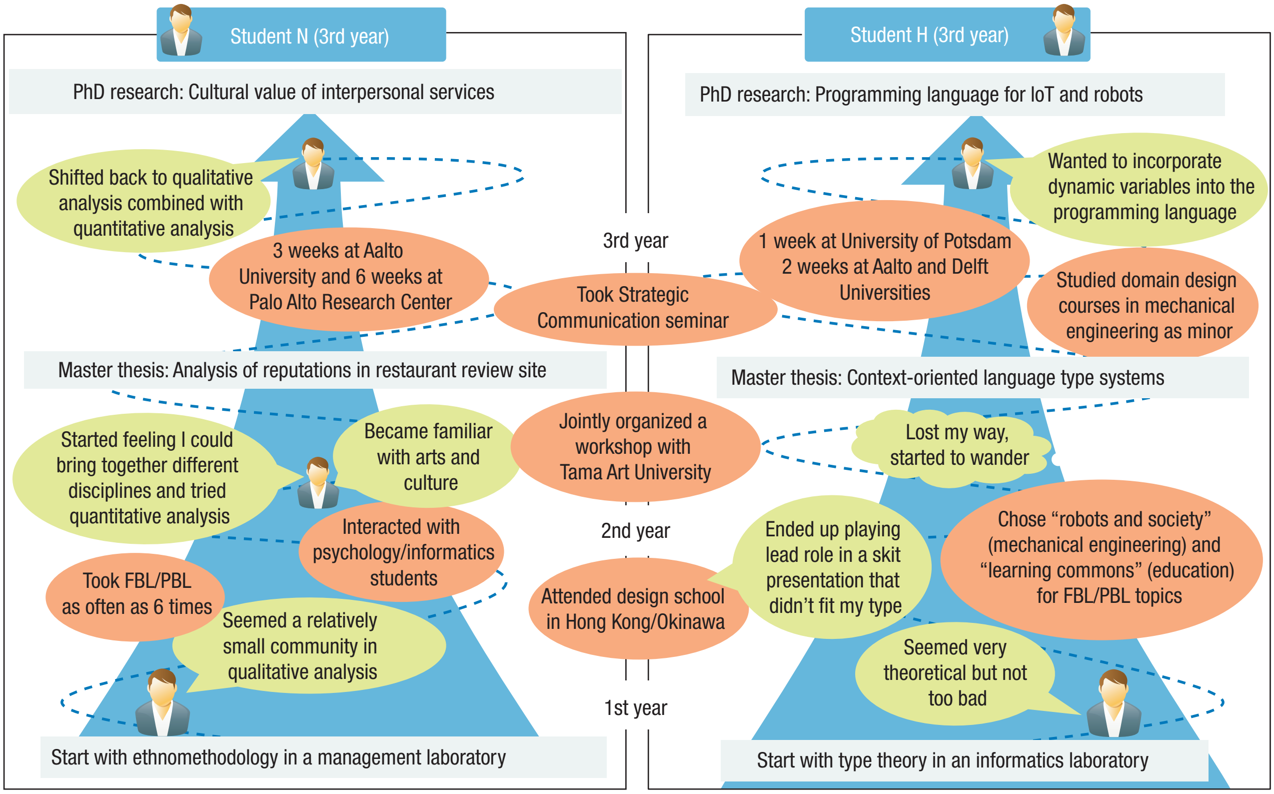


**FIGURE 4.** Journey map for two Kyoto University Design School students deciding on a dissertation topic. The green bubbles represent the students' comments and thought processes through their three years, the orange ovals represent learning opportunities the students took, and the gray bars represent the students' research and academic milestones. Both students eventually chose a topic that was highly suitable for their respective majors but also connected to social issues. FBL: field-based learning; IoT: Internet of Things; PBL: problem-based learning.

and attributes that they will learn in coursework and collaborations and that are in demand by a wide range of employers. In Figure 5, the radar chart for employers plots the ratios of industry and government employers that strongly or moderately expect each competence to be fostered by the students during the course study to the total number of respondents. The increasing student ratio for competency milestones is evidence that students steadily gain confidence in their abilities and eventually surpass the ratio of employers who desire these competencies.

The Kyoto University Design School is evolving, but establishing design studies as an academic field will require three key actions. The first is to create an abstraction of domain-dependent design theories and methods, and their transition to other fields. The second is to articulate objectives for the abstracted design methodologies so that domain-dependent design theories and methods can be instantiated. Finally, there must be a thorough investigation of the underlying concepts in design studies and the creation of an interdisciplinary vocabulary. A single university cannot implement these actions successfully. Rather, there must be an influx of feedback from and involvement of faculty members involved in design studies worldwide.

Often, science and engineering are treated as contrasts, with the notion that science is for understanding the essence of phenomena and engineering is for creating technologies that benefit society. However, engineering researchers do more than that and so should be viewed as creating a cycle of science and engineering. At the same time, design has been considered as an element of engineering that leads to the development of technologies that serve society. In today's world of complexly intertwined problems, however, design should not be thought of as merely the applied stage of engineering. Instead, researchers should take up the academic challenge of establishing the realm of design studies and generating a cycle of science, engineering, and design.

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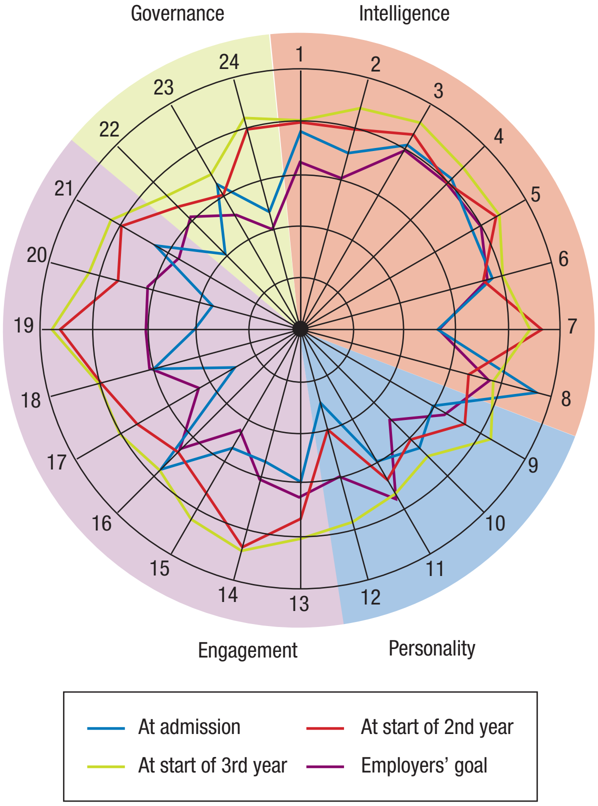


| | Competency milestone |
|---|---|
| 1 | Recognizes significance of own and related subject areas in a wider social context |
| 2 | Accesses and collects appropriate sources of relevant data from observation |
| 3 | Recognizes and validates basic research questions to be addressed |
| 4 | Has core knowledge and basic understanding of key concepts |
| 5 | Evaluates the impact and outcomes of own research activities linking with real world affairs |
| 6 | Creates ideas and approaches by investigating and seeking information within own research area |
| 7 | Critically analyzes and evaluates existing products and social systems |
| 8 | Develops awareness of the impact of research on wider society and vice versa |
| 9 | Demonstrates self-discipline and motivation for own research |
| 10 | Recognizes boundaries of own knowledge and develops awareness of need to gain support |
| 11 | Develops international contacts and networks to engage with and understand other cultures |
| 12 | Acts with professional integrity and honesty in defending ideas |
| 13 | Builds collaborative relationships to share understanding with a range of colleagues |
| 14 | Actively participates in and contributes to collaborations and external relationships |
| 15 | Articulates ideas clearly and effectively to a diverse and nonspecialist variety of audiences |
| 16 | Appreciates and works with diversity and difference in multicultural contexts |
| 17 | Demonstrates initiative and competence in leading people engaged in group activities |
| 18 | Understands leadership in team environments to effectively achieve mutual goals |
| 19 | Motivates and encourages team members |
| 20 | Coaches team members and helps them clarify their roles and responsibilities |
| 21 | Actively engages in knowledge exchange with team members of different disciplines in both public and business sectors |
| 22 | Develops understanding of own research under a broader context and draws up long-term plans |
| 23 | Applies effective project management |
| 24 | Grasps funding processes by writing own research proposal and managing own grant |

**FIGURE 5.** Design innovator index. The index is used to measure students' progress in four areas—intelligence, personality, engagement, and governance—in terms of competency milestones achieved. At admission and the start of their second and third years, students are asked to rate their confidence in achieving the 24 competency milestones. The wheel shows the ratio of the students checking affirmative with strong confidence and affirmative with moderate confidence to the number of students enrolled. By the third year, most students had more confidence than potential employers expected.

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