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Article

Integrating Data Science into Project-Based Learning for Regional Problem Solving: A Practical Case Study

Yasuki Tsuchiya * and Ken-ichi Yasue

Faculty of Sustainable Design, University of Toyama, Toyama 930-8555, Japan; yasueken@sus.u-toyama.ac.jp
* Correspondence: ytsuchiya@sus.u-toyama.ac.jp; Tel.: +81-76-445-6011

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Abstract: Regional universities are increasingly expected to contribute to local problem-solving while cultivating practical competencies in students. However, effectively integrating data science (DS) into Project-Based Learning (PBL) remains challenging due to operational and institutional barriers. This study presents a practical framework for "DS-enhanced PBL" based on the educational practices at the School of Sustainable Design, University of Toyama. In the "Regional Design PBL" course, students collaborate with local governments and private sectors to address real-world issues. To overcome the high technical barriers for students and the instructional workload for faculty, we introduced a "circulating support" model led by a dedicated DS instructor. Through the analysis of four representative cases—disaster information sharing, spatial evaluation of emergency supply warehouses, congestion mitigation in the university cafeteria, and wildlife monitoring using IoT—this study demonstrates how specialized technical support enables students to construct evidence-based arguments and develop feasible regional proposals. The findings suggest that a systematic support structure is a decisive factor in sustaining interdisciplinary DS-oriented PBL, offering a viable model for advancing data-driven higher education in regional settings.

Keywords: Project-based learning (PBL), Data science education, GIS analysis, IoT monitoring, Regional problem solving

1. Introduction

1.1. Trends in Data Science Education in Japan

In Japan, the development of professionals who can understand data science (DS) and artificial intelligence (AI) and apply these skills within their respective professional fields has been positioned as a key national policy goal. According to the Japanese government's AI Strategy 2022, formulated by the Cabinet Office, the cultivation of DS- and AI-literate professionals capable of cross-disciplinary application is identified as a central objective of national education and innovation policy (Cabinet Office, 2022).

To promote this goal, the "Mathematics, Data Science, and AI Education Program Certification System" has been established, and universities across the country have been advancing data science education under this framework. Among these programs, particular emphasis has been placed on the applied foundational level, where practical competencies are fostered through exercises and Project-Based Learning (PBL).

To support nationwide implementation, the Japan Inter-University Consortium for Mathematics, Data Science and AI Education has been organized as an interuniversity initiative to assist universities in developing distinctive DS education programs. However, surveys conducted by the consortium indicate that challenges remain, including securing instructors with sufficient expertise and designing effective group work. As a result, establishing practical and sustainable models for the effective integration of DS into PBL continues to be difficult (Consortium for Strengthening Mathematics, Data Science, and AI Education, 2025).

The difficulties in establishing these models are largely attributed to the scarcity of human resources, including the securing of instructors with sufficient expertise, the considerable effort required for course preparation, and the need for high-level facilitation skills among faculty. In particular, the lack of instructors who can bridge the gap between theoretical DS and its practical application in regional contexts remains a critical bottleneck. This study presents a case at the University of Toyama where these challenges were addressed by introducing a dedicated faculty member specializing in DS support. We argue that securing such dedicated personnel is essential for facilitating the effective use of DS within PBL.

Accordingly, this study aims to clarify how DS can be effectively integrated into Project-Based Learning (PBL) through an analysis of educational practices at the University of Toyama and to offer practical implications for its implementation.

1.2. Significance of Data Science in Regional Design Education

The University of Toyama, where the authors are affiliated, is a national university in Toyama Prefecture, Japan, and the School of Sustainable Design comprises three departments: Materials Engineering, Earth System Science, and Urban and Transportation Design. One of the core objectives of our faculty is to cultivate human resources capable of addressing regional and societal challenges using data.

In the context of regional problem solving, DS serves as an important means for understanding and analyzing spatial structures, human behavior, and related phenomena. By utilizing spatial data, statistical data, and behavioral data, it becomes possible to develop evidence-based proposals, thereby enhancing the persuasiveness and feasibility of design outcomes. Nevertheless, how DS should be integrated into PBL while balancing educational effectiveness and operational feasibility remains an open question, particularly in interdisciplinary educational environments.

1.3. Literature Review and Purpose of This Study

Previous studies on Project-Based Learning (PBL) have widely demonstrated its effectiveness in enhancing problem-solving skills and promoting interdisciplinary learning. For example, PBL has been shown to be effective in fostering students' ability to integrate and apply knowledge and skills within contexts that closely resemble real-world situations (Kolaczyk et al., 2021). In the context of DS education, the introduction of PBL has also been found to improve students' problem-solving abilities, deepen their understanding of learning content, and enhance learning motivation (Huang et al., 2022; Clausen et al., 2025).

On the other hand, numerous challenges related to operational and institutional aspects have been reported in the practice of PBL with DS as a core component. Studies focusing on Japanese universities have pointed out that, in large-scale PBL-oriented online DS courses, it is difficult to secure sufficient specialized technical support, manage the increased instructional workload of faculty members, and design effective mechanisms to promote collaboration among students (Sakamaki et al., 2022).

Nevertheless, in higher education, there remain relatively few practical cases in which DS has been systematically and continuously integrated into PBL with clearly defined institutional support structures. In large-scale and interdisciplinary educational environments, how to incorporate specialized DS support while balancing educational effectiveness and operational feasibility has yet to be sufficiently examined.

As described above, while previous studies have highlighted the importance of PBL and the integration of DS, they have also identified significant challenges in course design and implementation. This study is positioned as a proposal for practical solutions to these operational and institutional challenges.

Against this background, the School of Sustainable Design at the University of Toyama has implemented a PBL course titled "Regional Design PBL," which focuses on real-world regional issues and is characterized by the active use of DS. This paper reports practical cases from this course and examines how DS is integrated into PBL through educational and institutional support. By presenting four representative case studies, this study aims to provide practical insights into the design and operation of DS-enhanced PBL for regional problem solving.

2. Overview of the Regional Design PBL

2.1. Course Design and Instructional Structure

The Regional Design PBL is a compulsory course offered in the third quarter of the third year (October–November) to approximately 160 students across the three departments of the School of Sustainable Design at the University of Toyama. The course is taught by 12 instructors representing all departments, and students are assigned to interdisciplinary groups of about seven to eight members. This mixed-team structure encourages cross-disciplinary collaboration and enables students to address multifaceted regional issues through diverse analytical and design approaches.

The course follows a design-thinking cycle—observation, analysis, ideation, prototyping, and evaluation—which is repeated throughout the eight-week period. Students conduct fieldwork, engage with local stakeholders, and iteratively develop two rounds of prototypes. Midterm poster sessions and final oral presentations are attended by faculty members, municipal officers, companies, nonprofit organizations, and residents. This structure provides authentic feedback loops and situates the learning process within actual community contexts.

The instructional design assigns one instructor to each project theme, who acts as a facilitator supporting team progress and coordinating with external partners. However, as instructors typically supervise two student groups while also managing local collaborations, the workload is substantial. This challenge was later addressed by introducing dedicated DS support, discussed in Section 2.3.

Student performance is evaluated through two main components: short reports submitted after each class and the final presentations. These are assessed by multiple instructors using a standardized rubric, which consists of two primary categories: (1) Technical Skills, such as presentation quality, report clarity, persuasiveness, and response to questions; and (2) Content Quality, which evaluates whether students followed the design-thinking process (observation, analysis, and ideation) to develop concrete prototypes. The integration of DS specifically contributes to enhancing the "persuasiveness" in technical skills and the "analysis" in content quality.

2.2. Past Themes and Educational Philosophy

Since 2020, the Regional Design PBL has addressed a wide range of real-world regional issues in collaboration with local governments, community organizations, companies, and university partners. As an illustrative example, Table 1 presents an overview of the project themes implemented in the 2023 academic year. 12 themes were offered, including renewable energy utilization, tourism development, branding of local agricultural products, public transportation strategies, disaster resilience, resource circularity, and behavioral analysis on campus (e.g., student cooperative cafeteria operations).

Table 1. Project themes of the Regional Design PBL in the 2023 academic year.

ID	Project Theme	Region
A	Exploring the Potential of Power Generation Using Temperature Differences	Toyama Prefecture
B	How Can Underutilized Resources in Toyama Be Leveraged to Attract Tourists?	Toyama Prefecture
C	Developing New Ideas for the Effective Use of Heavy Snowfall in Toyama	Toyama Prefecture
D	Strategies for Enhancing and Communicating Regional Attractiveness through the Fugan Canal	Toyama City
E	Branding Hatomugi (Job's Tears) as a Local Agricultural Product	Himi City
F	Transport-Oriented Community Development Utilizing Diverse Local Resources and Public Transportation	Takaoka City
G	What Can We Do to Achieve Inclusive Disaster Preparedness That Leaves No One Behind?	Tonami City
H	Proposing Solutions to Regional Challenges through Resource Circularity	Nanto City
I	Toward the Realization of Rice Paddy Art through the Utilization of Fallow Farmland	Toyama City
J	Exploring Ways to Secure Local Mobility for Daily Outings in Rural Communities	Asahi Town
K	Identifying Issues and Proposing Solutions for the University of Toyama Co-op Based on Data Analysis	On Campus

These themes reflect the program's educational philosophy:

1. Cultivate interdisciplinary problem-solving skills by engaging students from different academic backgrounds in collaborative design tasks.
2. Promote evidence-based regional design through the integration of spatial data, statistical analysis, and qualitative field insights.
3. Encourage iterative learning through multiple rounds of prototyping and evaluation with authentic stakeholders.

The final deliverables, compiled annually into "Regional Design PBL" report volumes, showcase not only the solutions proposed but also the analytical and design processes students experienced.

2.3. Data Science Support System

Students receive foundational DS education during their first three years, including courses in data engineering, introductory statistics, programming, and geographic information systems (GIS). Applying this knowledge to real-world regional issues, however, has proved considerably more difficult. In previous years, many students struggled at the stages of data acquisition and preprocessing. In addition, theme instructors are not always specialists in DS, which has at times limited the technical guidance they can provide.

To address these challenges, the School of Sustainable Design introduced a dedicated faculty position responsible for DS support in the 2023 academic year. Rather than overseeing a specific project theme, this assistant professor provides cross-cutting support by circulating among all student groups to facilitate the effective use of DS across PBL activities. Their responsibilities include the preprocessing and management of GIS and statistical datasets; design and demonstration of analytical workflows; technical consultation on AI, IoT, and data visualization; development of teaching materials; and real-time technical assistance. The introduction of this specialized role created a crucial synergy with the students' prior knowledge. While their foundational education alone was insufficient for independent application to complex regional issues, students possessed the necessary literacy to effectively utilize the instructor's support. For instance, most students already had basic GIS knowledge, enabling them to perform visualizations independently once provided with appropriate datasets. Moreover, the availability of institutional resources, such as faculty-wide ArcGIS licenses and the datasets introduced by the instructor, further enhanced this effectiveness. Thus, the program's success is attributed to the combination of students' educational background, available regional and institutional resources, and the technical assistance that bridged the gap between theory and practice.

This institutional support substantially lowered the barriers to DS utilization, enabling students to adopt more advanced analytical approaches such as spatial overlay analysis, IoT sensor data processing, clustering, and behavioral data interpretation. Instructors also recognized the involvement of DS expertise as essential for enhancing the feasibility, persuasiveness, and technical validity of student proposals.

To balance technical support with student autonomy, the DS instructor provides guidance on available datasets and potential directions for data visualization. However, such information is provided as suggestions rather than mandates. As this program is rooted in the principles of PBL, students retain full autonomy in determining their project's direction, and their decisions on whether to implement the instructor's technical advice are respected to ensure a student-led learning process.

Furthermore, starting from the 2026 academic year, the implementation period of the course is scheduled to be extended to two quarters (Q3–Q4). This extended timeframe is expected to allow greater allocation of time for data collection, analysis, stakeholder collaboration, and iterative prototyping. As a result, DS is anticipated to be positioned not merely as a supplementary tool, but as an integrated core component of the PBL process.

3. Case Studies

3.1. Case 1: Disaster Information Sharing after the Noto Peninsula Earthquake

In this case, the January 2024 Noto Peninsula Earthquake was selected as the project theme, with a particular focus on disaster damage mitigation. Based on interviews conducted with the Toyama Prefectural Disaster Prevention Center, the students identified delays in disaster information sharing as a critical issue to be addressed. Accordingly, they designed and developed a citizen-participatory disaster information sharing system.

Specifically, the system combined ArcGIS Online, which enables web-based visualization of GIS data, with the LINE messaging application. This configuration allowed citizens to submit disaster-related information through a dedicated form on their smartphones, and the submitted data were visualized in real time on an interactive map (Fig. 1).

Fig. 1. Citizen-participatory disaster information sharing system using ArcGIS Online. It is a web application in which information is mapped at the center, with statistical summaries displayed on the left and individual report details presented on the right.

In terms of instructional support, the theme instructor was responsible for coordination and communication with the prefectural government, while the DS instructor supported the technical design of the system. This support included demonstrating how ArcGIS Online could be effectively utilized and how user-friendly data submission forms could be implemented, thereby assisting students in developing the overall system architecture. Since the theme instructor did not specialize in the development of web-based analytical systems, the presence of the dedicated DS instructor was instrumental in realizing this outcome. This case demonstrates that the complementary role allocation between the theme instructor and the DS instructor was instrumental in proposing GIS-based solutions within PBL for regional problem solving.

3.2. Case 2: Spatial Evaluation of Emergency-Supply Warehouses

As in Case 1, this case study also focused on earthquake-related disasters. The objective was to examine the appropriateness of the locations of emergency-supply warehouses through spatial analysis using population distribution data and various hazard maps. The students overlaid the locations of emergency-supply warehouses with population density data, flood inundation areas, and earthquake damage estimation zones within a GIS environment. Through this analysis, they evaluated the accessibility of emergency supplies and potential risks during disaster situations (Fig. 2).

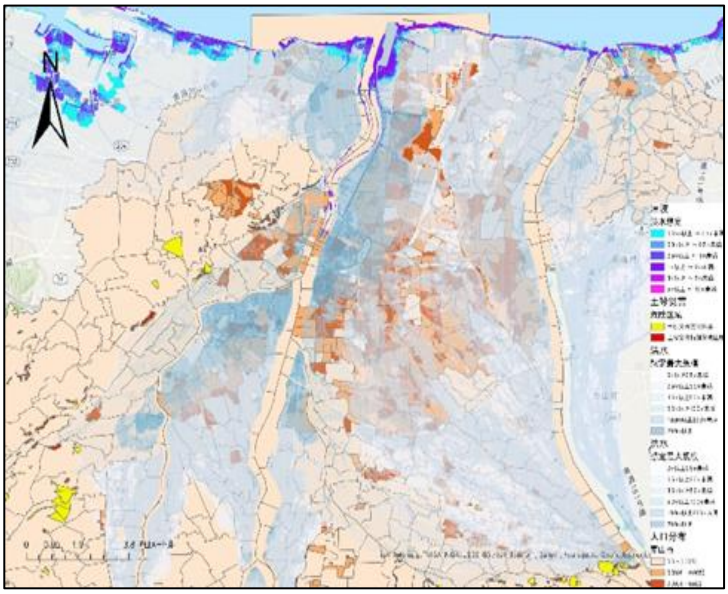

Fig. 2. Comparison with flood inundation hazard areas using GIS. Red indicates population distribution, light blue represents flood inundation areas, and dark blue denotes tsunami hazard zones.

Based on the analytical results, the students further proposed improvements to warehouse design and management practices by incorporating perspectives from materials engineering. This case demonstrates that integrating spatial data analysis with disciplinary expertise enables the development of more practical and persuasive disaster preparedness plans.

Regarding instructional support, the DS instructor provided guidance on identifying relevant GIS datasets and offered fundamental technical support for GIS analysis. Since the datasets are openly provided by the Japanese government, students compared their publication sources and examined methods for importing them into GIS software. By appropriately supplying such datasets, students became aware of the potential to analyze regional issues using data-driven approaches. These cases highlight the importance of data provision, demonstrating that equipping students with accessible analytical resources effectively expands the range of tools available for problem solving.

3.3. Case 3: Mitigating Cafeteria Congestion Using POS and Flow Data

This case study sought to alleviate congestion in the university cooperative cafeteria through behavioral analysis drawing on point-of-sale (POS) data and pedestrian flow camera records. By examining time-specific customer volumes and menu selection patterns, the students designed and implemented a targeted intervention to redirect demand toward a relatively less crowded curry counter.

The analysis confirmed a certain degree of behavioral change; however, a substantial reduction in congestion during peak hours was not achieved. The DS instructor supported this project by assisting with the installation of pedestrian flow cameras and providing guidance on data analysis using spreadsheet software. Visualization through graphs enabled students to clearly interpret and communicate their analytical results (Fig. 3).

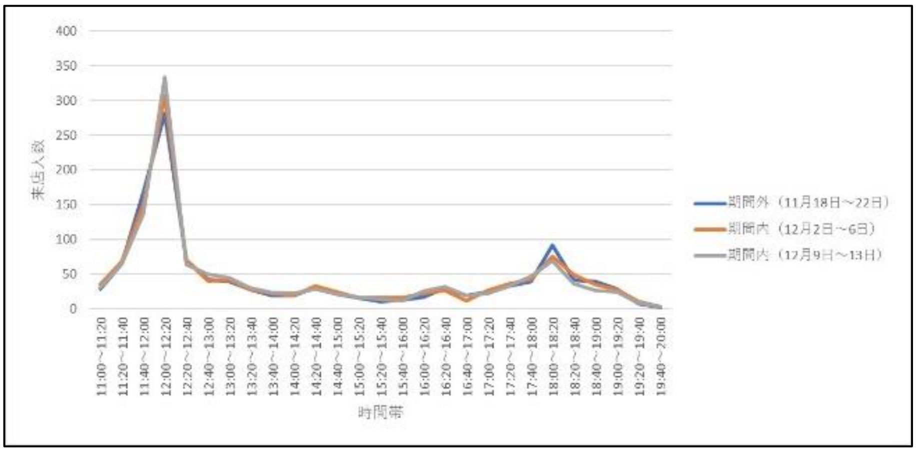

Fig. 3. Temporal trends in the number of cafeteria visitors by period. The blue line represents the pre-intervention period, while the orange and gray lines indicate the post-intervention period.

This case provided students with hands-on experience in evaluating the effectiveness of interventions based on empirical data, highlighting the importance of evidence-based assessment in problem-solving. The DS instructor provided the pedestrian flow cameras in advance, which made it possible to conduct the measurements. In addition, the instructor offered step-by-step guidance on data visualization using spreadsheet software. Meanwhile, the theme instructor was responsible for communication and coordination with the university cooperative and other collaborating partners. This case underscores the importance of clear role allocation between instructors as well as the significance of detailed, hands-on technical support in facilitating effective PBL implementation.

3.4. Case 4: Wildlife Monitoring with IoT Cameras in Mountainous Areas

This case study addressed wildlife damage in mountainous regions through the analysis of image data collected over approximately one year from ten IoT cameras installed in the study area. The students organized and analyzed animal appearance patterns by time of day, season, and species, quantitatively identifying and visualizing characteristics of wildlife-related damage (Fig. 4).

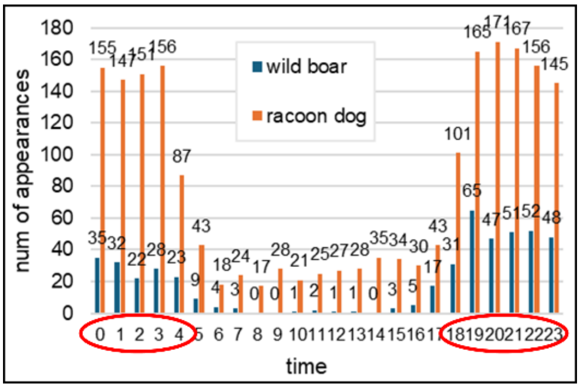

Fig. 4. Number of appearances of wild boars and raccoon dogs by time of day. The analysis indicates that raccoon dogs were more frequently observed during nighttime hours.

The analysis suggested that bait consumption by non-target species, such as raccoon dogs, was a contributing factor to reduced capture efficiency. Based on these findings, the students proposed countermeasures involving improvements to bait placement and operational practices.

The DS instructor supported this case by assisting with camera installation and data analysis using spreadsheet software. By visualizing the data from multiple perspectives—such as temperature, time of day, and season—using spreadsheet software, the students were able to better understand wild boar appearance patterns and to effectively examine potential countermeasures. This case demonstrates the importance of data visualization as well as the significance of providing appropriate support for visualization in data-driven problem solving.

4. Conclusions and Implications for Data-Science-Enhanced PBL

4.1. Key Strategies for Integrating Data Science into PBL

This study identified several key strategies for effectively integrating DS into Project-Based Learning (PBL) focused on regional problem solving.

First, reducing the technical barriers associated with GIS was essential. This was achieved by preparing collections of past project examples, providing continuous instructional support, and organizing accessible GIS datasets in advance. These measures enabled students to focus on analytical thinking and problem formulation rather than on technical difficulties related to data handling.

Second, structured support for statistical and quantitative analysis was provided. Instructors prepared basic analytical settings and demonstrated representative analysis workflows, while also offering guidance on analytical directions when necessary. This approach helped students who lacked confidence in data analysis to engage with quantitative evidence more effectively.

4.2. Educational and Practical Outcomes

Through these strategies, several educational and practical outcomes were observed. Students developed stronger analytical skills and demonstrated an improved ability to construct evidence-based arguments when addressing regional issues. The integration of DS expanded the range of solution approaches available to students, allowing them to explore regional problems from multiple quantitative and spatial perspectives.

A key limitation of this study is the lack of quantitative evaluation results. Because each PBL project theme is unique, standardizing quantitative measurements across groups is methodologically challenging. Consequently, the significant improvements in student learning outcomes observed by the instructors following the integration of DS have not yet been systematically quantified.

Despite this limitation, some student groups continued their projects beyond the course period, leading to presentations at academic conferences and further research activities (Yamasaki et al., 2025; Kimura et al., 2024). These tangible outcomes suggest that DS-enhanced PBL can foster not only short-term learning gains but also longer-term academic and practical engagement.

4.3. Importance of Institutional and Human Support

The findings of this study also highlight the critical importance of institutional and human support in implementing DS-enhanced PBL. Assigning personnel with strong expertise in DS as dedicated support staff proved effective in lowering the entry barriers for students. With appropriate guidance, students were able to engage with advanced analytical methods without being overwhelmed by technical complexity.

In large-scale and DS-enhanced PBL environments, such support structures are particularly important. Rather than relying solely on individual instructors, a system that distributes technical expertise across projects can improve both educational effectiveness and operational feasibility. These results indicate that institutional arrangements play a decisive role in sustaining DS-oriented PBL initiatives.

Although this study is based on a case analysis at a single university, the proposed model offers highly applicable insights for other institutions. Our university does not possess an extraordinary IT infrastructure or a specialized DS research department. While it is unrealistic to expect all faculty members to become experts in DS, our "circulating support" model—where a single specialist provides cross-cutting assistance—presents a feasible organizational structure for other universities with limited human resources.

We have disseminated these achievements through published case reports and through site visits from other educational institutions, whose favorable responses indicate that the model is transferable. Adoption requires only one faculty member specializing in DS. Although securing several faculty members who can apply DS or GIS in PBL education is difficult, requiring only one substantially widens the range of institutions that can implement the approach.

As demonstrated in the case studies, the introduction of a dedicated DS instructor enabled students to effectively visualize complex datasets (Case 2) and quantitatively evaluate the potential impacts of their proposals (Case 3)—tasks that were previously beyond their reach. Such data-driven approaches were not observed prior to the appointment of the specialized faculty member.

To further validate these outcomes and assess the generalizability of this model, future research should incorporate quantitative assessments, such as student surveys or pre- and post-intervention evaluations, as well as comparative studies across multiple institutional settings and longitudinal follow-up studies.

In conclusion, this study presents a practical and institutional framework for integrating DS into regionally oriented Project-Based Learning (PBL). As outlined in Section 1.3, while prior studies have demonstrated the effectiveness of DS-enhanced PBL, they have also consistently identified the scarcity of specialized human resources as a primary bottleneck. By proposing and validating a "circulating support" model, this study addresses these operational and institutional constraints. This model offers a viable, scalable implementation framework that overcomes these limitations, providing a practical solution for advancing data-driven higher education in regional settings.

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Conflicts of Interest: The authors declare no conflicts of interest.

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