Proceedings of the ASME 2020
International Design Engineering Technical Conferences
and Computers and Information in Engineering Conference
IDETC/CIE2020
August 16-19, 2020, St. Louis, MO, USA

DETC2020-22669

METHOD SELECTION IN HUMAN-CENTERED DESIGN TEAMS: AN EXAMINATION OF DECISION-MAKING STRATEGIES

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ABSTRACT

Designers' choices of methods are well known to shape project outcomes. However, questions remain about why design teams select particular methodsand how teams' decision-making strategies are influenced by project- and process-based factors. In this work, we analyze novice design teams' decision-making strategies underlying 297 selections of human-centered design methods over the course of three semester-long project-based engineering design courses. We propose a framework grounded in 100+ factors sourced from new product development literature that classifies design teams' method selection strategy as either agent-, outcome-, or process-driven, with eight further subclassifications. Coding method selections with this framework, we uncover three insights about design team method selection. First, we identify fewer outcomes-based selection strategies across all phases and innovation types. Second, we observe a shift in decision-making strategy from user-focused outcomes in earlier phases to product-based outcomes in later phases. Third, we observe that decision-making strategy produces a greater heterogeneity of method selections as compared to the class average as a whole, or project type alone. These findings provide a deeper understanding of designers' method selection behavior and have implications for effective management of design teams, development of automated design support tools to aid design teams, and curation of design method repositories, e.g., theDesignExchange.

1. INTRODUCTION

Human-centered design (HCD) is used to address a range of problems, from machine design to complex sociotechnical challenges [1,2]. The HCD process is not monolithic, however, and researchers have catalogued hundreds of distinct design methods that enable HCD, typically organized across phases of Research, Analyze, Ideate, Build, and Communicate [3,4]. Design methods play a key role in HCD, because, as Keinonen writes, they help designers formalize attempts "to bridge the emerging conceptions of new design and actual design practice" [5–7]. Design methods are, as Lai writes, "a solid first step," but require that practitioners be ready to adapt as they encounter challenges across design phases [8].

Design method selection can shape outcomes across all phases of the design process, [9–12], making method selection a crucial aspect of successful design work. Recent scholarship has explored how to best support designers as they select methods, as effective support of designers' design decisions could have a high impact on project outcomes. However, significant questions remain about why design teams select particular methods and how teams' decision-making strategies are influenced by project- and process-based factors.

To explore this, we investigated the following research questions in this work:

- **R1.** How does the prevalence of decision-making strategies used by design teams differ across **design phase**?
- **R2.** How does the prevalence of decision-making strategies used by design teams differ across **innovation types?**
- **R3. What elements** of the design team's decision-making strategy drive teams' selections of methods?
- **R4. What is the relative influence** of decision-making strategy and innovation type on a design team's selection of methods?

In this paper, we first review related work in design methods and decision-making that motivate our study (Sec. 2). We then describe the framework we developed to describe team decision-making strategy (Sec. 3) and introduce research methods (Sec. 4). In Sec. 5, we describe four key results from our work that address our research questions above and proceed to discuss their implications for design practice, design team leaders, and automated design support tools (Sec. 6).

2. RELATED WORK

In this section we review related work on identifying design methods and their selection by design teams. We also briefly review work on design team decision-making.

Design methods, method selection, and selection support

Since their formalization at the seminal *Conference on Design Methods* more than 50 years ago [13], design methods have become central to design research [14]. In practice, professionals search for design methods based on the expected outcome and rely on personal contacts to explore new methods [12]. While many design methods are newly proposed to support designers, transferring methods to design practice beyond research has proved challenging [15–19]. Several efforts have emerged to catalogue methods in a practitioner-friendly format, ranging from industry initiatives such as IDEO's Design Kit (formerly HCD Connect) [20] to the TheDesignExchange.org [3,4]. TheDesignExchange is the largest open-source repository of design methods, and has been built to support design practitioners to explore and implement methods in their practice, as well as share results as case studies to the public [4].

Studies of how such compendia of methods are used revealed patterns among designers' selections of methods. Analyzing data from IDEO's HCD Connect platform, Fuge discovered that designers use research-phase methods more frequently, with the individual interview being the most popular method out of 39 methods total [21]. Fuge also described which methods are typically applied together, both within design phase and beyond it. In other work, Fuge explored how design method selections correlated to the topic of a design project - e.g., agriculture or community development - finding several methods uniquely tied to design project topic [22].

Building on understanding what methods designers select, researchers have explored how to *help* designers navigate the design process. A range of stimuli and support tools have been proposed, from automatic analogical reasoning support [23] to cards to facilitate creativity in designing for cybersecurity [24]. Among support tools, automated tools to help designers are of particular interest. Fuge developed a machine learning-based method selection tool to suggest methods to designers, discovering that knowing how often methods are used together creates more effective suggestions than methods suggestions based on project content alone [25]. Haider reported an approach to utilize case studies in order to suggest design methods [26]. In examining a classic engineering design problem, truss loading, Raina developed a deep learning agent trained on human designers' on-screen behavior in designing trusses to support design decisions [27]. While not explicitly engaged with HCD, Raina's contribution blended human behavior (e.g., screen behavior) in addition to human action (e.g., truss outputs) to develop design support. Many other studies seek to help designers in real-time by providing adaptive support based on what designers do, such as Goucher-Lambert's study of real-time adaptive stimuli for ideation [28] and Zabotto's automated mood board generation system [29].

These contributions show that studies of method selection and designer behavior have focused on *what* designers did in solving design problems - what methods they selected, or what design artifacts they produced in real time. However, these approaches are often tied to highly specialized problem spaces or environments. In order to create more effective and generalizable automated design support tools, a deeper understanding of *why* designers took particular actions is essential. An understanding of why designers engage in specific actions could enable nuanced adaptive support, and such support would be based on design strategy rather than design activity.

To explore this, Poreh investigated novice designers' rationale in method selection [30]. This research revealed that student teams align their method choices with various types of project's contextual characteristics: socio-technical, industry domain, user base, and benefit of a particular method. Yet, dealing with selecting appropriate design methods and motivation around the selection process over the design journey is challenging and unknown. Poreh analyzed the first three phases of the design process: Research, Analyze, and Ideate. In this work, we seek to build on Poreh's research by developing a framework to describe designers' decision-making strategy in method selection and expand the scope of analysis to include the Build and Communicate phases of the research.

Design team decision-making

Decision-making in design is an essential facet of innovation and problem-solving, with studies exploring its role in fields from naval architecture [31] to strategic business decisions [32]. Design can be represented as a sequence of decisions that result in a designer's desired outcome [33–36], and understanding decision-making is a crucial precursor to establishing agent-based or statistical decision support in design [36]. Raina uses the term *strategy* to refer to a "policy, plan, or process heuristic" for sequencing decisions in solving problems. While Raina is referring explicitly to computational agents, the term is used to describe the transfer of human design strategies to computational agents. Raina's research focused on technical engineering design problems, while here we adapt the term *decision-making strategy* to explore the policies and factors that motivate teams to make the decisions that they do, with a specific focus on design method selection as the decision investigated.

3. FRAMEWORK DEVELOPMENT

Decision-Making Strategy

In order to describe decision-making strategies, we first established a framework to classify distinct strategies emergent in design teams. We established a context model for the framework development process, first listing 100+ context factors described as essential in product design, product innovation, and new product development (NPD) literature, chosen for their foundational relevance to engineering design. For example, from management scholarship, Kimberly mentions *Leadership, Competition, User Age*, and *Size of the Team* [37]. Meanwhile, Balachandra, in the electrical engineering literature, describes *Market Existence, Technology,* and *Environmental Support* as contextual factors of innovation [38]; further references elicited a range of factors, from *Task Structures* to *Marketing Synergy* [39–47]. Several factors overlapped, despite being titled differently by various scholars. To manage overlap, two researchers with at least two co-authored publications in engineering design theory research, clustered factors using affinity diagramming.

Affinity diagramming resulted in three higher-categories (Agent, Outcome, Process) and eight sub-categories (Individual agent, team agent, user outcome, market outcome, technical outcome, product outcome, resource-related process, constraint-related process). This developed into our framework for classifying design team decision-making strategy (Table 1).

TABLE 1. DECISION-MAKING STRATEGY

Code	**Subcode**	**Context**
Agent (A)	Individual (A1)	● Personal interest ● Intrinsic motivation ● Willingness to try ● Familiarity ● Self-efficacy
	Group (A2)	● Group diversity ● Size of the team ● Specification of members ● Communication ● Team centralization
Outcome (O)	User (O1)	● Customer characteristics ● User age/location
	Market (O2)	● Market existence/size ● Industry factors ● Utility value/market type
	Technology (O3)	● Availability of technology ● Simple/complex to realize
	Product (O4)	● Product specific ● Characteristic/type/use
Process	Resource (P1)	● Type of supervision ● Supportive behaviors ● Spatial configuration ● Fairness climate
	Constraint (P2)	● Deadline/remained time ● Rewards ● Evaluation ● Task complexity

To classify design team decisions, we simplified descriptions of each strategy. Below are the final (higher) category definitions that were used during the data coding process.

- **Agent:** If a decision is centered around an Agent, it means that the focus is on the person (A1) or the group of people (A2) who were responding to the decision (e.g., Designer A chose to use laser cutting because they were familiar with the technique).
- **Outcome:** If a decision is centered on an Outcome, it means that the team's decision was motivated by the expected product-use context such as end user characteristics (O1), market situation (O2), technological advancement (O3) or specific product use (O4) (e.g., Team B developed a wireframe because describing the workflow to a user was very important)
- **Process:** If a decision is based on Process, it means that the organizational elements such as positive resources and gain (P1) or constraints (P2) have a strong influence (e.g., Team A chose to use laser cutting because the project deadline was in two days).

Classifying Design Team Projects by Innovation Type

Several approaches have been previously proposed to classify design team projects. Lande described manufacturing process, assessment tools, products, and human-centered design products as categories to describe the nature of design team projects [1]. Fuge classified human-centered design for development projects by their focus area, which ranged from community development to energy [22]. Rather than anchor in the topic of a design project, we seek to understand at a more general level the type of *innovation* a team is pursuing as a way to categorize team projects. We rely on a four-level typology proposed by Ceschin [48]: Product innovation, Product-Service innovation, Spatio-Social innovation, and Socio-technical System innovation. By categorizing projects by innovation type rather than output or content, we can seek patterns between projects that may differ substantially in application area.

4. METHODS

In this section, we describe our data collection approach, the novice student design context in which data was collected, and our approach to coding and classifying data.

4.1 Data collection

We collected data from three project-based design courses at a major research university in the United States over a three-year period (2017, 2018 and 2019). A total of 88 students in 21 teams

(Table 2) learned and practiced the HCD process in a 2-credit six-week intensive format, which corresponded to 30 hours' total instruction, and an expected 60 hours of out-of-class work. Student teams selected their own project topics in response to an open-ended design prompt, which was articulated "Choose a compelling problem you experience in your daily life." The class had a sequenced one week-long focus on each of the five design phases: Research, Analyze, Ideate, Build and Communicate. Midterm deliverables were a design review and prototype, and final deliverables were a high-fidelity prototype and presentation encapsulating their work. Students used *TheDesignExchange.org*, a large open-source, online innovation repository of design methods and case studies [3,4], to learn a variety of design methods to practice in the context of a semester-long design project. In each phase, teams selected three design methods from a subselection of methods from theDesignExchange and explained their choices in a short written justification. A total of 60 methods from the design exchange were available for design teams to choose from, an average of 12 methods per design phase. Between years, course curriculum and learning materials were consistent. Two instructors, both with design practice and academic design research experience, instructed various sections of the course.

In 2018, data from the fifth phase (Communicate) was not available. Collected data was anonymized and incomplete data was removed. A total of 297 team method selections, representing a 100% response rate from teams, and associated explanations formed the data set used for analysis. The average length of explanation was 77 words (SD = 51).

TABLE 2. BREAKDOWN OF PARTICIPANTS

Year	# of Teams	# of Students	Demographic Information
3	9	33	• 19 male and 14 female students • 22 international and 11 domestic
2	6	28	• 15 male and 13 female students • 8 international and 20 domestic
1	6	27	• 15 male and 12 female students • 13 international and 14 domestic
Total	**21**	**88**	

4.2 Data analysis

The data-sets were coded by two designers with experience in academic design research and industry design practice, both experienced in design process, methods, and engineering education. The decision-making strategy framework (Table 1) was used to code team explanations of why a specific method was chosen. One coder evaluated data from years one and two. The second coder recoded 10% segments of the coded data until an acceptable interrater reliability (IRR) of 0.86 between coder one and two was achieved. IRR of at least ≥ 0.7 was achieved for each of the Agent-, Outcome-, and Process-focused strategies. The second coder coded the year three data set. Table 3 shows examples of student response and its corresponding coding.

Table 3: REPRESENTATIVE STUDENT RESPONSE

Category	Student Response
Agent (A)	*I chose this design because this suits my visual learning from me drawing out my data instead of writing it out (A1)* *As a group, we discussed which all methods we had available to us and came to a consensus on using composite characters after light discussion after realizing this was different enough from the other methods in order to not be redundant. (A2)*
Outcome (O)	*I chose this method because it enables the researcher to identify new opportunities in the market, which is an aspect of this design challenge. (O2)* *We all agreed that competitive analysis would allow us to similarly explore a wide range in the technology sphere. (O3)*
Process (P)	*The method is used for rapidly expressing the concepts. Sometimes it is hard for teammates to understand each others' ideas by words, so it is a good idea to use it to communicate the concepts better. (P1)* *We also thought it would be easy for all members to work on together and only requires affordable materials ... it is also an efficient and cost-effective way to collect and organize information about users, goals and tasks. (P2)*

TABLE 4. INNOVATION TYPE AND EXAMPLES.

Innovation Type	#	Example Project
Product	7	A device to help users keep their valuables safe when enjoying live events.
Product-Service	7	A service to help artists and creators keep track of their ideas and continually be inspired.
Spatio-Social	7	An augmented reality (AR) safety network that utilizes the existing framework of street lamps to increase safety and security through smart navigation.
Socio-Technical System	0	-

Team project final and interim deliverables from the three course offerings were reviewed holistically and double-coded for classification by Ceschin's innovation typology (Table 4).

Because data on the fifth phase, Communicate, was not collected in 2018, we have left this phase out of cohort-wide discrete data analysis, e.g., Fig. 3. However, for proportionate data analysis, we do examine the Communicate phase.

4.3 Method Distance Parameter

In order to compare the effect of decision-making strategy and innovation type on method selection, we introduce a metric, the *method distance parameter*, which allows us to compare the proportion of a given method's selection by factor (e.g., decision-making strategy) in a given phase with the proportion of a method's selection overall in a given phase. By examining differences in factor-based proportions from the overall mean, we establish the method distance parameter, $D_{Mod,i,C}$:

$$D_{Mod,i,C} = abs\left(\left(\frac{\sum_{C=1}^{3} N_{Mod,i,C}}{\sum_{i=1}^{M}\sum_{C=1}^{3} N_{Mod,i,C}}\right) - \left(\frac{N_{Mod,i,C}}{\sum_{i=1}^{M} N_{Mod,i,C}}\right)\right) \qquad (1)$$

Where *Mod* is the design phase, from 1 through 5, corresponding to the Research through Communicate phases; *C* is the factor level, from 1 through 3, representing either agent, process, and outcome or the three innovation types; *N* is the number of times the *i*th method in a phase was selected under a certain factor; and *M* is the number of methods available to be chosen in a certain phase. For example, $D_{1,1,1}$ is the method distance parameter for the first method (i = 1) of the first phase (*Mod* = 1, Research phase) by the first factor (*C* = 1, corresponding to agent). For example, $D_{1,1,1}$ examines the first method in the first phase (the 1:1 Interview). It measures the difference between the proportion of methods selected in phase one using the agent-driven decision-making strategy represented by the 1:1 interview, and the proportion of methods selected in phase one overall represented by the 1:1 interview.

The method distance parameter is a comparison of proportions. Instead of comparing a z-statistic for each individual pairing, we calculate the absolute value difference of the proportions, and then perform standard hypothesis testing approaches on the distribution of proportion differences to determine the significance of difference between decision-making strategy and innovation type's effect. The magnitude of the method distance parameter to ascertain how substantial the result is.

5. RESULTS

In this section, we consider dynamics of method selection strategy between phases (R1), and examine the relationship between method selection strategy, project type (R2), and the design method selected (R3, R4).

TABLE 6. DECISION-MAKING STRATEGY

Factor		Agent	Outcome	Process
Overall		117	72	108
by Design Phase	Research	25	17	21
	Analyze	26	16	21
	Ideate	28	5	30
	Build	17	24	22
	Communicate	21	10	14
by Innovation Typology	Product	40	28	31
	Product-Service	43	25	28
	Spatio-Social	34	19	49

5.1. R1: Outcomes-driven selection is less used than other decision-making strategies, except in the Build phase.

Among overall findings (Table 6), agent- and process-driven method selection were used more than outcomes-driven method selection (Fig. 1a). A pairwise proportion test revealed significant ($p < 0.05$, Holm-adjusted) differences, with a small effect size according to a Cohen's *h* test, between A-O (*difference* = 0.15, *h* = 0.33) and O-P (*difference* = 0.12, *h* = 0.26) proportions.

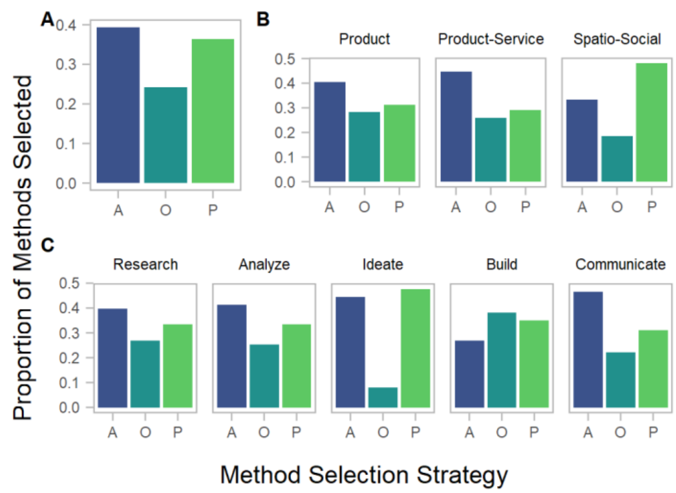

Figure 1. Team selection behavior, overall (a), by project type (b), and phase (c).

Across innovation types (Fig. 1b), a pairwise proportion test revealed three significant ($p < 0.05$, Holm-adjusted) differences between selection strategies with effect size of medium or greater, all between the outcome-focused strategy in Spatio-Social innovation and agent-focused strategies in (1) Product (*difference* = 0.22, *h* = 0.49) and (2) Product-Service (*difference* = 0.26, *h* = 0.57), and (3) process-focused strategy in Spatio-Social innovation (*difference* = 0.29, *h* = 0.64). Across all design process phases (Fig. 1c), a pairwise proportion test revealed six significant ($p < 0.05$, Holm-adjusted) differences between selections with effect size medium or greater: between (1) outcome-focused strategy in the Ideate phase and (2) the agent-focused strategy in the Research (*difference* = 0.32, *h* = 0.79), Analyze (*difference* = 0.33, *h* = 0.82), Ideate (*difference* = 0.37, *h* = 0.89), and Communicate (*difference* = 0.25, *h* = 0.66) phases, the process-focused strategy in the Ideate phase (*difference* = 0.40, *h* = 0.95), and the outcome-focused strategy in the Build phase (*difference* = 0.30, *h* = 0.76).

5.2. R2: Spatio-Social innovation projects exhibit unique distributions of decision-making strategy.

Spatio-Social typologies show a different distribution of decision-making strategy from other types, with nearly 50% of methods being chosen for process-driven factors (Table 4, Fig. 1b). A closer examination of underlying trends show that five of seven teams pursuing Spatio-Social innovations exhibit selection behavior indicative of the process-dominated overall trend **(Fig. 2)**. Using a pairwise proportion test, the observed differences were found not to be significant ($p > 0.05$, Holm-adjusted), so our analysis of Fig. 2 is descriptive.

Figure 2. Spatio-Social teams selection behavior.

These findings indicate that design teams' method selection is primarily (~75%) driven by organizational (process-driven) and team (agent-driven) factors, rather than factors related to the outcome of the design project, such as the user, technology,

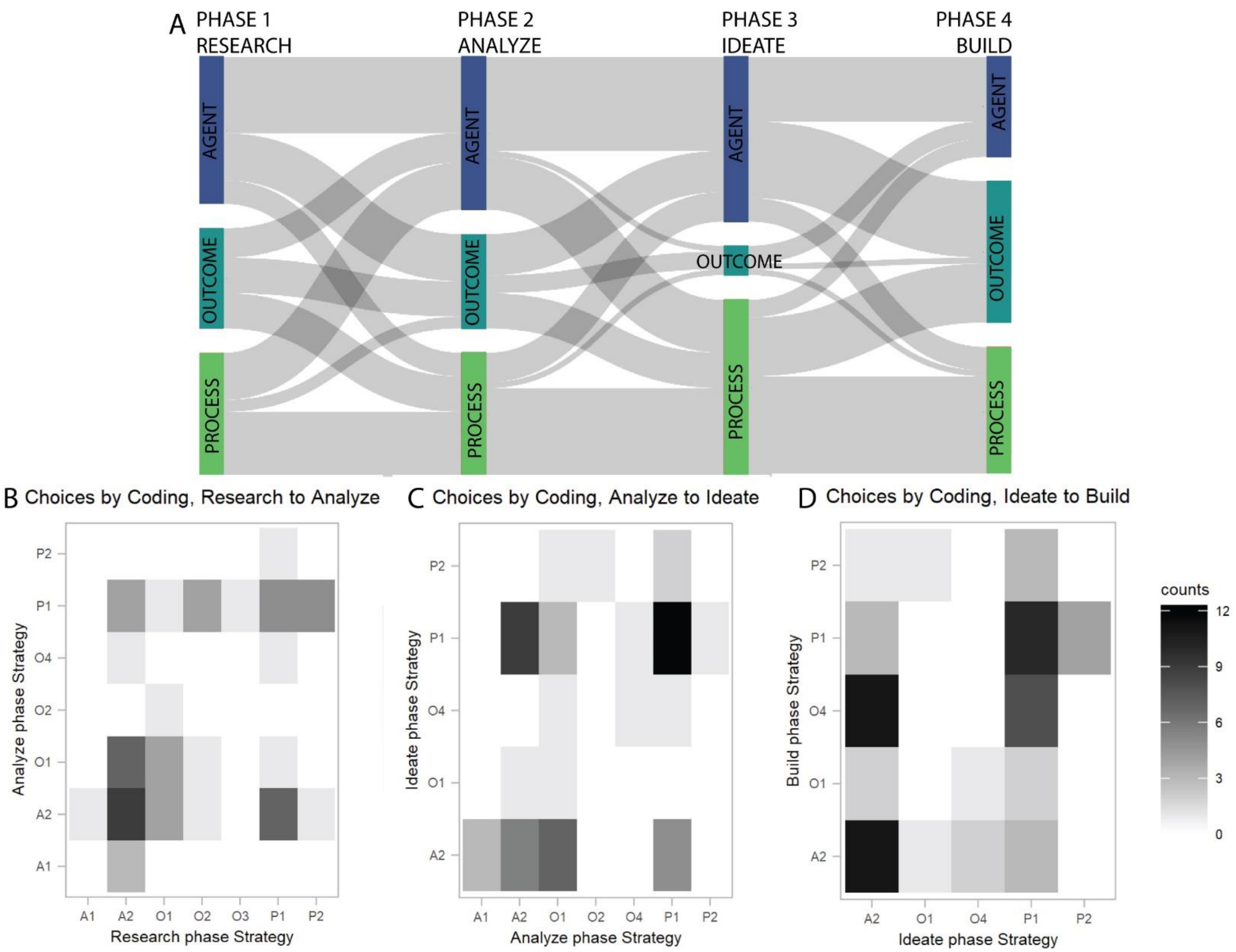

Figure 3. Method selections by particular strategy and relationship to in the subsequent phase's method selection strategy (a). More detail between phases is shown **(b-d);** for example, teams' decision-making strategies in the Research phase (x) are mapped against teams' strategies in the next phase, analyze (y), with darker squares indicating more frequent pairs of decision-making strategies between phases **(b)**. Due to incomplete data, the communicate phase is not shown.

market, or product itself. Outcome-driven method selection in phase three, Ideate, accounted <10% of methods chosen.

5.3. R3: Method selection between the Analyze through Build phases highlights a change in outcome-driven method selection from a user to product focus.

The relationship between method selection strategies in each phase (Fig. 3a) emphasizes the reduction in outcome-driven method selection between phase 2 and phase 3, but also its growth from phase 3 to phase 4. Looking at specific sub-categories, we see that in the phase 1-2 transition (Fig. 3b), user-focused factors (code O1) account for almost all of the outcomes-driven method selections. The phase 2-3 transition (Fig. 3c) is characterized by movement between team-focused agent-driven factors (code A2) and gain-focused process-driven factors (code P1), as well as a smaller but important shift from code O1 to codes A2 and P1. The growth of outcome-driven factors between phase 3 and phase 4 (Fig. 3d) is driven by a shift from A2 and P1 factors to product-focused process-driven factors (code O4). This analysis only reveals trends between two phases, and does not distinguish trends beyond that (e.g., relating phases 1 and 3).

This trend in method selection strategy illustrates a pathway of teams' consideration of outcome-oriented method selection, and is further evidenced by the specific methods each team chose (Fig. 4). Teams begin phase two, Analyze, with user-focused outcomes, choosing methods such as Empathy Maps and Customer Journey Mapping. In the transition to phase three, Ideate, teams de-emphasize user-focused outcomes as they select methods such as Brainstorming and 6-3-5 Brainwriting. In phase four, Build, teams' method selection strategies have a renewed outcome-driven emphasis, but are centered on product-focused outcomes, leading teams to select methods like tangible prototypes and wireframes. In phase four, O1 codes notably converged on the Experience Prototype method.

5.4. R4: Method selection by decision-making strategy differs more from the global average method selection than method selection by project type

We examined how frequently methods are selected within each module. We compare: (1) the proportion of overall methods selected accounted for by a given method, with (2) the proportion of agent-, outcome-, or process- specific method selections represented by the given method (Fig. 5), and (3) the proportion of methods selected in Product, Product-Service system, and Spatio-Social innovation projects represented by the method (Fig. 6). For example, the 1:1 Interview was a popular method in Phase 1, accounting for a proportion of 0.19 of all methods selected in Phase 1. Among process-driven methods selected, coded 'P', however, the 1:1 Interview was even more popular, accounting for a proportion of 0.286. In contrast, among outcome-driven and agent-driven methods selected, the 1:1 Interview represented proportions of 0.176 and 0.12, both below the overall average.

Considering innovation type, among Product, Product-Service, and Spatio-Social innovation types, the 1:1 Interview accounted for proportions of 0.143, 0.190, and 0.238, respectively.

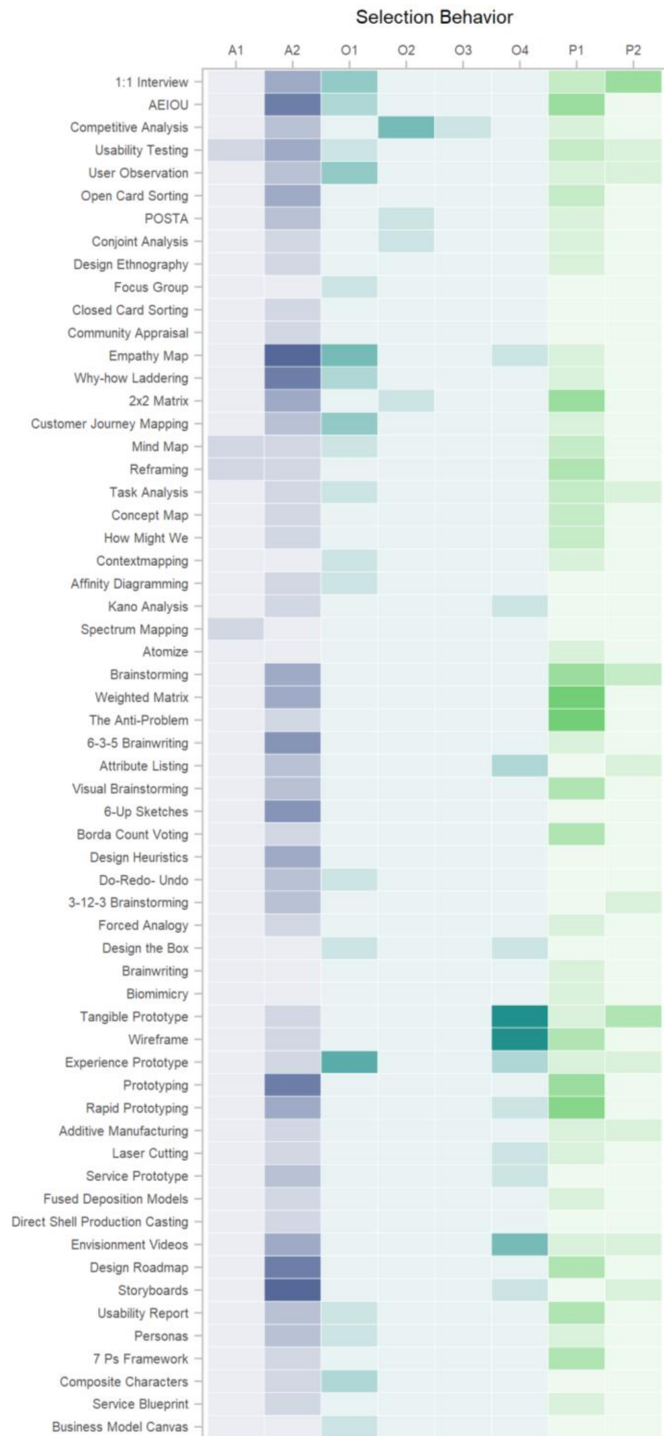

Fig. 4. Method Selection Frequency.

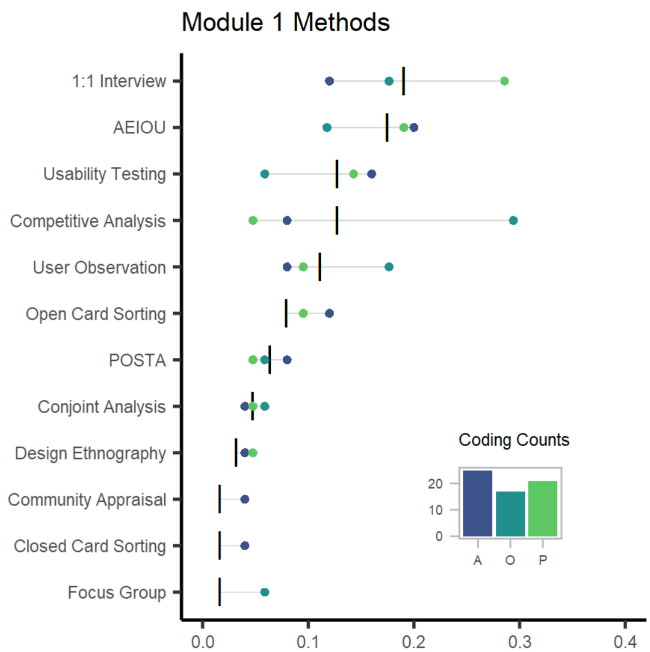

Fig. 5. Method Selection by Decision-making Strategy.

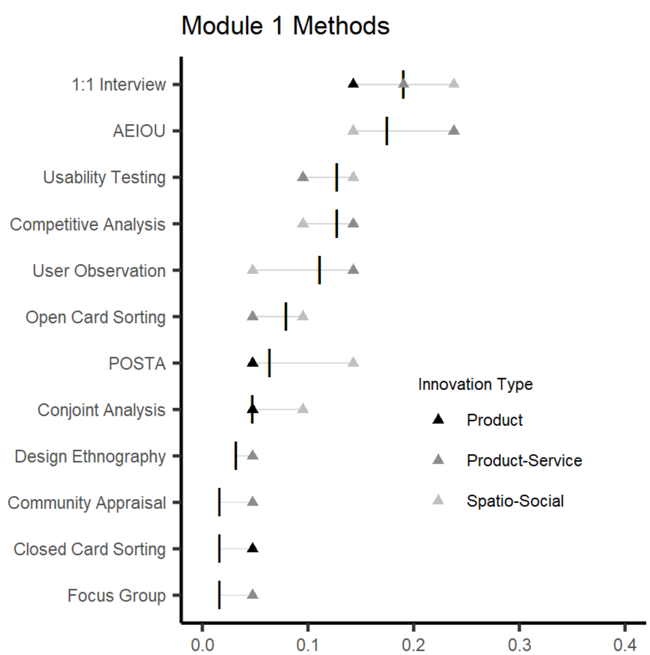

Fig. 6. Method Selection by Innovation Type.

6. DISCUSSION

In this section, we consider the implications of findings reported in the previous section. We address each research question in light of overall findings.

6.1. R1. Absence of outcome-focused selection strategies

Considering Fig. 1a and Table 4, it is evident that method selection among teams observed is primarily driven by agent- (39.4 % of total) and process-driven (36.4%) factors, rather than outcome (24.2%). While the effect size is small, pairwise proportion tests are significant, indicating that this difference is real. Much of method selection in novice design teams appears to be governed by individual or team dynamics (agent) or contextual factors (process). This suggests that design teams' decision-making strategy is less anchored in design project outcome – a surprising result, especially in human-centered design projects, where the emphasis is often on user-oriented outcomes [49,50]. This result further highlights the well-established importance of team and contextual factors in team decision-making, such as psychological safety and constraints [51,52].

Exploring decision-making dynamics further, we observed that there are several opportunities to support designers, especially during the Ideate phase (Fig. 1c), where less than 10% of methods selected were outcome-driven, the pairwise proportion test was significant, and effect size was medium to large. First, for innovation and design teams, this suggests that encouraging greater focus on outcomes of work in the ideation phase could ensure goals of the overall project are considered alongside team and context factors during method selection. Studies often emphasize the importance of time constraints in the design process [53] and ideation quantity [54,55]. These tendencies could have an influence on the decision-making strategy of design teams, by shifting their attention away from the end-user or desired outcome and towards considerations of what is most effective for the team given constraints and requirements. This finding adds effects on team decision-making strategy to the dialogue around constraints in design, and in ideation in particular [56,57].

6.2. R2. Method selection strategies among innovation types

Spatio-Social projects exhibit a different distribution of method selection compared to other project types, with the highest incidence of process-focused decision-making strategies and the lowest incidence of outcome-focused strategies (Fig. 1b). This trend is further evident among Spatio-Social projects (Fig. 2). We reiterate that the differences in observed counts were found not to be significant in a pairwise proportion test, but this is in large part due to the small number of counts (15) per team; our discussion is grounded in a descriptive analysis.

These trends suggest that Spatio-Social teams have trouble focusing their decision-making strategy around outcomes when selecting methods. One explanation for this is that Spatio-Social projects are inherently complex in their scope, outcomes, and constituent factors [2,48,58], and could complicate teams' abilities to consider outcomes while engaging in the design process. Revisiting the agent-outcome-process framework, Spatio-Social projects may pose particular challenges in articulating discrete users, markets, and technologies, and may not immediately invite discussion about specific products or interventions.

Spatio-Social teams' engagement with process-focused methods-selection is especially notable during the Analyze phase, when teams engage with sensemaking. While Product and

Product-Service teams were mostly grounded in agent-focused method selection (47% of all methods selected for both project types), Spatio-Social teams demonstrated process-driven method selection (57%). This influences differences in methods selected. In the Analyze phase, Empathy Maps represented the most popular method for agent- and outcome-driven method selection. However, in process-driven method selection, Empathy Maps ranked seventh. In contrast, the most popular methods among process-driven method selections was the 2x2 Matrix, a tool widely acknowledged for helping make complex problems more accessible [59]. The 2x2 Matrix ranked third among agent- and outcome-driven teams. This suggests that innovation type influences teams' decision-making strategies, and different decision-making strategies lead teams to select different design methods. Spatio-Social innovation teams exhibit very different decision-making strategy patterns than the other two innovation types, explaining some of the difference observed in method selection by innovation type.

Another possible influence is the composition of design teams, which in our data is drawn from novice designers. Expert designers are known to take greater time in engaging with tasks [60] and have been shown to tolerate a higher degree of complexity and uncertainty [61]. Both of these characteristics are particularly relevant to articulating an outcome-focused decision-making strategy in Spatio-Social innovation projects, which present design teams with high levels of complexity. Novice designers' decrease readiness in these areas may result in their lack of ability of engage with outcome-focused strategies in complex projects. However, we also highlight that despite the likelihood of experts' higher readiness to engage with challenging aspects of Spatio-Social innovation, even expert designers face challenges in finding a shared language to discuss methods amid uncertainty in the design process [10,62]. This suggests that despite outcome-focused decision-making strategy, unifying strategies with methods would still be of great value to experts.

6.3. R3. Shifts from user- to product-focused outcome focus.

While many teams do not change their decision-making strategy between phases (e.g., staying with decision-making strategy A2, team-focused), we focus on those who do (Fig. 3b-d). In particular, the movement towards O1 codes - user-focused outcomes - in the Analyze phase, followed by a movement towards O4 codes - product-focused outcomes - in the Build phase highlight a common understanding of how design team focus shifts during the design process. In early stages of the design process, design teams are focused on user needs, while later, they focus on developing a specific product [63]. While it is well-understood that key *activities* in early- to late-stage design follow a user- to product-focus trajectory, it is surprising to see this mirrored in the decision-making strategy of teams. For example, in the Build phase, this suggests that teams are considering their product, rather than their user, in deciding what methods best express prototypes of their projects. Lauff describes prototypes as tools to help design teams communicate, learn, and decide [64]; if methods to do so are selected with a focus on product rather than other outcomes, teams may be missing opportunities to leverage prototyping methods to communicate and learn holistically about their product. These findings further reinforce the need for support during the prototyping phase that helps a team craft their thinking behind method selection, such as the Prototyping Canvas and the Prototype for X framework [65,66].

Similar analysis can be applied to other phases to reveal opportunities to support teams. In the Analyze phase, teams can be encouraged to consider other aspects of outcomes besides users as they pursue sensemaking activities. Implications of shifts during the ideation phase were addressed earlier. Such support would help ensure that teams engage with the holistic aspects of human-centered design, considering a variety factors beyond a singular product or user focus.

An examination of method selection frequency by phase (Fig. 4) reveals several notable findings. First, we are struck that teams rarely select methods because of an outcome-focus on market (O2) or technology (O3). Four methods were selected with O2 or O3 codes: Competitive Analysis, POSTA, Conjoint Analysis, and the 2x2 Matrix. Of these, Competitive Analysis was the only method code O3 was associated with. Course material involves examples of products, services, and experiences currently on the market (e.g., Jerry the Bear by Sproutel [67–69]) and discusses underlying technologies (e.g., bluetooth for IoT systems [70]). That students rarely incorporate such thinking into method selection suggests that they need support to map design process onto technology and market domains [71]. We also note that of these methods, Competitive Analysis, 2x2 Matrix, and Conjoint Analysis are methods that have been adapted from the fields of business strategy and product development, suggesting that students could associate these methods with these fields.

A second finding from Fig. 4 is that students select different prototyping methods in the Build phase with different strategies. Most notably, Tangible Prototyping and Wireframing were most frequently selected with an outcome-focus on product (O4). Meanwhile, Experience Prototyping was most frequently selected with an outcome-focus on user (O1). Both methods, however, are powerful means of representing a product's function, form and role, to use Houd and Hill's framing of the uses of prototypes [72]. This distinction suggests there are student preconceptions about the value prototyping methods might deliver their team. To challenge these preconceptions, design team leaders could challenge teams to consider all aspects of outcome when selecting methods.

6.4. R4. Differences in method selection patterns between innovation type and decision-making strategy

We observe decision-making strategy to explain more of the difference in teams' method selections from the cohort average than innovation type (Fig. 5, Fig. 6). Our work extends on Fuge's results that designers' method selections correlated with project type [21,22,25]. While Fuge's work examined project topic, we find that innovation type appears to influence decision-making strategy, shaping methods selected. Innovation type alone, however, makes less of a difference than decision strategy.

This added nuance to the relationship between design project and method selection extends the broad themes identified by Fuge, while enabling a different path to automated method selection. A support tool, in addition to processing project content and adjacent method selected as previously suggested, could also incorporate measures of design phase and current decision-making approach by the team. This offers a more comprehensive approach to automated design support that could serve to ensure that design teams engage with a diversity of methods in the course of their projects. Furthermore, by associated design phase, innovation type, and decision-making strategy, automated support tools could be generalized to address a variety of design problems, rather than remaining topic-specific or context-specific. Strategy is a concept transferable to various design contexts, as is innovation type. This is especially urgent as designers are increasingly tasked with solving complex sociotechnical problems.

These findings highlight the potential of a deeper understanding of decision-making strategy in design teams. By understanding the reasoning behind designers' behavior, future tools can be more effective at adaptively supporting design activities in a variety of contexts. We believe a closer investigation into decision-making strategy across a variety of design activities, not just method selection, can help make adaptive and automated design support more nuanced and more effective.

7. LIMITATIONS

This research has several important limitations. First, course data was collected over a three-year period, featuring two separate instructors. Student cohorts from year one and year three, for example, might have been exposed to slightly different class content, in turn potentially altering their method selection strategy. In the design and roll-out of each course, however, materials were shared between instructors, and the sequencing of data collection for each class was constant.

Second, a key assumption in this work is that methods were selected by teams with thoughtful review, and not randomly or unilaterally selected. Part of our research instrument is designed to ensure this is the case: each team crafted a justification for why they chose a given method. The survey and justification were scored for all participants on a team, giving each member an incentive to participate in method selection and justification. However, we acknowledge that some teams may have behaved more randomly, or perhaps did not thoroughly review all of the methods options before making a choice.

Finally, we code team justifications of method selection for the most heavily represented decision-making strategy. In cases where elements of more than one code were evident, the most heavily-represented code was assigned. We expect future studies can examine the multiple dynamics at play throughout the course of the class.

8. CONCLUSIONS

This work presents an analysis of team decision-making strategy in selecting methods in human-centered design projects. We present a framework for describing team decision-making strategy and apply it to three years' worth of data from a project-based engineering design course. We examine the influence of project type, as described by the scope of the innovation pursued, and design phase, as outlined by theDesignExchange. We find that both design phase and project type influence the decision-making strategies adopted by teams, which in turn shapes the design methods that teams select.

Four results were salient. We observed that teams practice outcomes-focused method selection less than agent- and process-focused methods, a difference especially notable during the Ideate phase. Second, we observed teams engaging with Spatio-Social innovation projects exhibited different decision-making strategy than teams exploring other innovation types. Third, we observed a shift from user-focused outcomes to product-focused outcomes as teams navigated the design process. Finally, we observed that decision-making strategy could explain heterogeneity in teams' method selections more than project type.

All four results have important implications for design team leaders and applications in the development of automated design support tools. We introduce decision-making strategy as a key factor in method selection, and design activities more generally. By understanding the rationale for design team decision-making, and its relationship to project phase and project type, automated support tools could more effectively guide and inspire designers as they envision future products, services, systems, and experiences. We hope to extend this work to professional and expert designers in future work.

ACKNOWLEDGMENTS

The authors acknowledge George Moore and Danielle Poreh for their assistance in developing and conducting the method selections surveys foundational to this work. This work is partially support by a Seed Grant from the Center for Long-term Cybersecurity (CLTC) at UC Berkeley.

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