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Developing the Design Reasoning in Data Life-Cycle Ethical Management Framework

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Developing the Design Reasoning in Data Life-cycle Ethical Management Framework

Abstract

Human-designed systems are increasingly leveraged by data-driven methods and artificial intelligence. This leads to an urgent need for responsible design and ethical use. The goal of this conceptual paper is two-fold. First, we will introduce the *Framework for Design Reasoning in Data Life-cycle Ethical Management*, which integrates three existing frameworks: 1) the design reasoning quadrants framework (representing engineering design research), and 2) the data life-cycle model (representing data management), and 3) the reflexive principles framework (representing ethical decision-making). The integration of three critical components of the framework (design reasoning, data reasoning, and ethical reasoning) is accomplished by centering on the conscientious negotiation of design risks and benefits. Second, we will present an example of a student design project report to demonstrate how this framework guides educators towards delineating and integrating data reasoning, ethical reasoning, and design reasoning in settings where ethical issues (e.g., AI solutions) are commonly experienced. The framework can be implemented to design courses through design review conversations that seamlessly integrate ethical reasoning into the technical and data decision-making processes.

1. Introduction

What does conscientious design and innovation mean for engineers today and in the near future? Engineers are continuously utilizing ever-expanding datasets and sophisticated artificial intelligence algorithms. These algorithms are used to generate design alternatives and optimize existing designs and systems [1]. In this new landscape, we need to re-examine the critical value engineers add by decision-making, negotiating constraints, and evaluating alternative solutions. We argue for a need to emphasize conscientious design, which encompasses evidence-based and user-centered design ideas and prioritizes ethical integrity and future perspectives. This emphasis may call for a renewed examination of the ABET criteria that emphasizes ethics in engineering education. The ABET criteria require engineering students to demonstrate the ability to recognize ethical and professional responsibilities when making informed judgments and ensuring consideration of the impact of the solutions across economic, environmental, and societal contexts [2].

Conscientious, ethical engineering design starts by responsibly curating, sharing, using, and contributing to the growing body of data, particularly with the ever-increasing utilization of big data and artificial intelligence tools during design processes [3]. There have already been numerous reported computer algorithm biases that systematically discriminate against certain content, individuals, or groups and that have had severe impacts on society due to effects of autonomous vehicles, credit scores, health care services, law enforcement, hiring practices, etc. [4] - [9]. Ethical data life-cycle management is the roadmap for handling data responsibly at all stages of its life-cycle to ensure accuracy, legality, fairness, privacy, and security [10], [11]. Engineering students, therefore, need to build proficiency and competencies in ethical data management as a requisite for ethical design.

Our aim is to investigate the integration of ethical reasoning and data reasoning into engineering design processes. Often, the competencies for such integration are learned through practice. However, a framework can guide the scaffolding of these practices and help navigate the ethical and data complexities. This conceptual paper aims to describe the development of Design Reasoning in Data Life-cycle Ethical Management Framework.

In engineering design education, the framework provides a structured approach facilitated by specific tools for curriculum and instruction, allowing mentors such as faculty, design coaches, and reviewers to integrate ethical and data considerations, as depicted in Figure 1. Evidence of design, ethical, and data reasoning competencies is demonstrated through students' language and discussions in both formal and informal design review conversations, as well as in their design products and final technical reports.

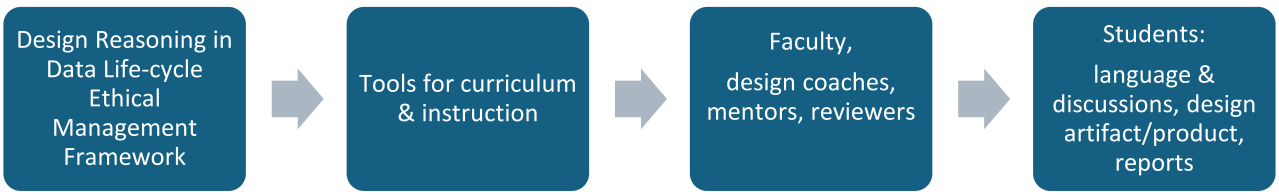

Figure 1: Design Reasoning in Data Life-cycle Ethical Management Framework within Engineering Design Education

2. The Status of Ethics and Data Education in Engineering Design

Ethics education is often separated from technical content in engineering design and data science education. To address the ABET criteria emphasizing ethics in engineering education, many engineering institutions implement standalone ethics courses or integrate engineering ethics into core courses [10], [13], [14]. In their review, Hess and Fore [15] identify common methods for integrating ethics into engineering, such as exposing engineering students to codes/standards, utilizing case studies, and engaging in discussion activities. For example, Kirkman [16] proposes a design ethics course that immerses students in complex problem situations and also highlights the parallel between ethical problem-solving and the design process. This course provides engineering students with the ability to frame and reframe problems, develop options, and organize and interconnect ethical values based on the options by introducing the concepts of ethical values, frameworks, and appropriate terminology [16].

Fore et al. [17] introduced an ethical framework called Integrated Community-Engaged Learning and Ethical Reflection (I-CELER) to enhance STEM ethics education by integrating ethical reflection into authentic learning experiences. Core concepts of the framework include ethical becoming, which emphasizes interpersonal interactions within a shared context and prioritizes ethical decision-making driven by care and concern rather than mere compliance. Additionally, the framework emphasizes experiential learning to enable the translation of theoretical concepts into practical application and foster reflection and ethical reasoning. Philosophical ethical theories such as Deweyian ethics and the ethic of care serve as tools for students to critically analyze ethical dilemmas and explain the ethical aspects of disciplinary practices. The framework adopts community-engaged learning, including service learning, as the preferred approach for creating an educational environment conducive to students' ethical practice, critical reflection, and ethical action [17]. Our conceptual study aims to complement these efforts in creating a framework for incorporating design, ethical, and data reasoning into instruction.

In addition to the need for ethical reasoning in engineering design education, data reasoning is crucial because engineering design increasingly utilizes data science methodologies. Data-driven design is becoming prominent due to developments in AI that harness data from various sources to make the design process more effective [3], [18]. In their research on rethinking engineering education, Broo et al. [19] suggest that next-generation engineers need proficiency in technologies such as artificial intelligence, machine learning, and data in order to advance the design, development, and manufacturing of new systems. Despite these technologies being taught mostly in computer science curricula than in engineering programs, the authors indicate that ethical considerations, biases, and social implications are often not adequately addressed in education [19]. One of the four identified strategies for higher education is to redesign their programs to incorporate "hands-on data fluency and management courses". They recommend that the recommended data fluency courses should include data management, statistics, machine learning, data ethics, and the social implications of future intelligent systems to manage the increasing complexity and sustainability of engineering systems [19].

3. The Design Reasoning in Data Life-cycle Ethical Management Framework.

The Design Reasoning in Data Life-cycle Ethical Management framework offers a conceptual structured and integrated approach to design, data, and ethical reasoning as a way to guide engineering design students during conscientious design. The framework also supports and equips research mentors (graduate students, post-docs, and faculty) to recognize, elicit, and foster ethical data and design decision-making within engineering design projects.

The Design Reasoning in Data Life-cycle Ethical Management framework is built by integrating three existing frameworks:

1. the Design Reasoning Quadrants Framework [20] which represents engineering design
2. the Reflexive Principlism [21] Framework, which represents ethical decision-making
3. the Data Life-cycle Model [22] which represents the big data life-cycle management

This framework reviews each design project with ethical principles as an overarching guide when making design decisions and managing data. The integration of the three critical components of the framework, i.e., design reasoning, data reasoning, and ethical reasoning, is accomplished by centering the negotiation of risks and benefits, an essential practice in engineering, as shown in Figure 2.

This negotiation of risks and benefits at the center of the framework emphasizes continuous dialogue of trade-offs across all design stages [23]. This approach recognizes design as a reflective and iterative process, where decisions are made within various constraints and informed by data and ethics. Engineer students engage in internal negotiation through reflective practices and externally through teamwork, client interactions, and stakeholder engagement.

They routinely assess and manage risks and benefits to prevent harm and enhance societal and economic value.

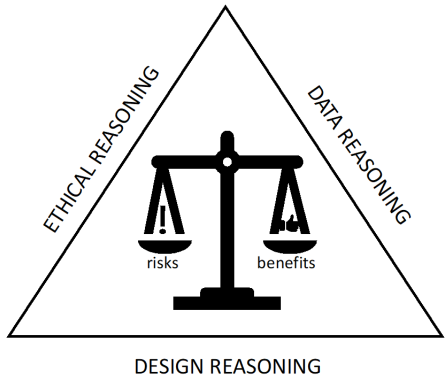

Figure 2. The Design Reasoning in Data Life-cycle Ethical Management Framework.

The following section briefly describes the three components of the Design Reasoning in Data Life-cycle Ethical Management framework.

3.1 Design Reasoning: The Design Reasoning Quadrants Framework

The Design Reasoning Quadrants framework proposed by Quintana-Cifuentes & Purzer [20] is a conceptual framework used to analyze and understand different forms of reasoning involved in the design process. It is represented by four quadrants, each reflecting a specific aspect of design reasoning. The quadrants are as follows:

- ***Experiential Observations***: In this quadrant, designers draw insights from their practical experiences and observations to inform their decision-making in the design process.
- ***Trade-offs***: In this quadrant, designers weigh the pros and cons of different design choices and make decisions that involve trade-offs between conflicting elements.
- ***First-Principles***: In this quadrant, designers rely on fundamental principles and theories within their discipline to guide their decision-making and problem-solving.
- ***Future Reasoning***: In this quadrant, designers engage in creative thinking and conceptualization to address novel challenges and develop innovative solutions. This involves reasoning that envisions new situations and deals with abstract and complex concepts.

The four quadrants stem from the intersection of two engineering practice dimensions proposed by Wolmarans [24] and rooted in Legitimation Code Theory [25]. The first dimension, Semantic Density (SD), spans from disciplinary to multidisciplinary knowledge, while the second dimension, Semantic Gravity (SG), ranges from theoretical understanding to practical experience. This intersection gives rise to four quadrants, as shown in Figure 3, where strong Semantic Density (SD++) encourages multidisciplinary thinking, while weak Semantic Density (SD--) indicates a singular disciplinary focus. Strong Semantic Gravity (SG++) relies on concrete clues over theoretical links, contrasting with weak Semantic Gravity (SG--), which leans toward theoretical and abstract reasoning [26]. The Design Reasoning Quadrants framework, emerging from these dimensions, offers a structured approach to categorize and analyze the diverse forms of reasoning in the design process.

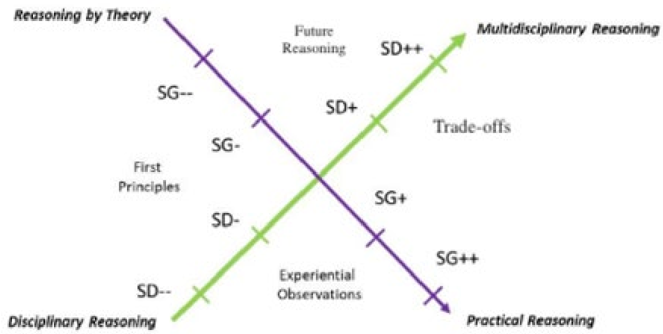

Figure 3: Design Reasoning Quadrants model adapted from Quintana-Cifuentes & Purzer [20, p. 1893]

3.2 Data Reasoning: The Big Data Life-cycle Model

The Big Data Life-cycle Model proposed by Pouchard [22] is a framework that outlines the stages involved in managing and curating Big Data throughout its life cycle. Big Data refers to the vast, complex datasets characterized by the 4 Vs, Volume, Variety, Velocity, and Veracity, which require specialized analysis tools and approaches.

This Big Data Life-cycle Model consists of several key activities, each playing a role in handling the different challenges posed by large and complex datasets [23, 24]. The following are the key components of the Big Data Life-cycle Model, as shown in Figure 4:

- ***Planning Activity***: This involves strategizing and outlining objectives related to handling Big Data by considering the volume, variety, velocity, and veracity of data.
- ***Acquiring Activity***: This is how data is produced, generated, and ingested in the research process. It involves data acquisition from various sources, considering quality-related challenges.
- ***Describing Activity:*** This is to document data sufficiently. Metadata, or data about data, is vital to data sharing and reuse.
- ***Preparing Activity***: This focuses on preparing datasets for analysis, including data wrangling and integration. It addresses the complexity of Big Data through reformatting, cleaning, and customization.
- ***Analyzing Activity***: This involves research through statistical methods and machine learning. It emphasizes the need for recording and preserving parameters for reproducibility.
- ***Preserving Activity***: This focuses on preserving results for long-term use, including creating pipelines or workflows. It addresses challenges in capturing and preserving interconnected processes in Big Data projects.
- ***Discover Activity***: This involves procedures to ensure the discoverability of datasets relevant to a particular analysis. It highlights the importance of data sharing and the role of repositories and standards.
- ***Assuring Activity:*** This is to employ quality assurance and quality control procedures. It identifies potential errors and enhances the quality of data.

Figure 4: The Big Data Life-cycle Model adopted from Pouchard [22, p. 184]

This Big Data Life-cycle Model serves as a guide for researchers, data managers, and librarians to plan and execute the workflow of managing and curating large and complex datasets. The model integrates research and data curation perspectives, emphasizing the interconnection of these activities. The 'Describe' and 'Assure' activities are highlighted as crucial components present at every step of the life cycle. The central cogs in Figure 4 represent the infrastructure supporting data held in cloud infrastructure, an institutional repository (IR), a disciplinary repository (DR), or a high-performance computing center (HPC) data facility.

3.3 Ethical Reasoning: The Reflexive Principlism Framework

Reflexive Principlism is defined by Beever & Brightman [21] as an approach to ethical reasoning aimed at providing a consistent and coherent framework for ethics education in engineering. It focuses on internalizing a reflective and iterative process of specification, balancing, and justification of four core ethical principles in the context of specific cases. The four core ethical principles include:

- ***Beneficence***: Preventing harm and providing benefits.
- ***Non-maleficence***: Avoiding the causation of harm.
- ***Autonomy***: Supporting and respecting autonomous decisions.
- ***Justice***: Fairly distributing benefits, risks, and costs.

Reflexive Principlism highlights reflectivity and signifies ethical decision-making as the process of evaluating statements and situations through inductive and deductive processes and ultimately achieving a coherent viewpoint through adjustments among theories, hypotheses, and experiments. It is also noted that the iterative nature of Reflexive Principlism, which continuously adjusts theories, hypotheses, and experiments to achieve the most ethical viewpoint, is compatible with the engineering design process.

During the engineering design process, beneficence guides students in prioritizing the prevention of harm and the provision of benefits to stakeholders, whereas non-maleficence emphasizes the importance of avoiding actions that could cause harm or identifying users who could be harmed. Autonomy emphasizes respecting individuals' right to make autonomous decisions regarding the use of engineering products or systems, while justice stresses the importance of fairness in distributing benefits, risks, and costs associated with engineering designs. Throughout the design process, engineering students should assess the potential harms and benefits associated with their designs and implement ways to mitigate them. By integrating these four ethical principles into engineering design, students consider the broader economic, environmental, and societal implications of their designs and strive to promote equity and inclusivity.

3.4 Example use of the Design Reasoning in Data Life-cycle Ethical Management Framework.

The Design Reasoning in Data Life-cycle Ethical Management framework offers a structured approach to fostering reasoning skills among engineering students engaged in design projects. Through a series of reasoning questions during formal or informal design review conversations, students are prompted to reflect on their design decisions while also considering data and ethical perspectives. These reasoning questions serve as a guide through which mentors demonstrate a genuine interest in understanding and evaluating students' work. With repeated exposure, students can develop the capability to ask reasoning questions themselves when implementing design projects. Additionally, the framework aims to cultivate reasoning fluency by empowering students to negotiate and reflect on the risks and benefits of their designs across design, data, and ethical perspectives. Educators can create an environment that promotes and facilitates reasoning, dialogue, and reflection by incorporating the framework into design coaching sessions and classroom discussions.

To illustrate the practical application of the proposed Design Reasoning in Data Life-cycle Ethical Management framework, let's examine a specific project. This project was done by a team of 7 undergraduate engineering students (four Computer, two Electrical, and one Industrial Engineering) as part of the program in the College of Engineering in which students receive academic credit for their work on authentic and long-term research and design projects.

Food Classification Project

An undergraduate research team is designing a mobile phone application that could classify different foods within an image taken by a phone. The team is planning to use a Convolutional Neural Network model to differentiate images and provide nutritional data to the users. This would allow users to have important information that could impact their health. The application that the students developed would allow the users to take the image and send it to the server where it was analyzed. The students could access food image databases to train their models to be able to classify the food. The students also incorporated food nutritional databases and guidelines to provide feedback.

The team developed a technical report detailing how they scoped the problem, the procedures they followed, and the solution they generated. Utilizing the text from the technical report, we formulated various reasoning questions to illustrate different components of Design Reasoning in Data Life-cycle Ethical Management framework, as shown in Table 1.

For instance, with the statement, "*The scope of this project is to identify food items in an image and report their nutritional content to the user*," we can pose the following reasoning questions:

"*What is the purpose of this product? Who will use it, and for what purpose? And who might be harmed?*"

The set of reasoning questions above is designed to illustrate and facilitate students' reflection on 1) the Experiential Observations quadrant of design reasoning, as the text involves practical experiences and observations, 2) the Planning Activity of data reasoning, as the text includes aspects of strategizing and outlining project objectives, and 3) the Beneficence principle within the ethics reasoning framework, as the text captures aspects related to preventing harm and providing benefits.

Table 1. Delineating and integrating design, data, and ethical reasoning in a project.

Text from a student technical report	**Design Reasoning in Data Life-cycle Ethical Management**			
	Reasoning Eliciting Questions	**Design Reasoning**	**Data Reasoning**	**Ethical Reasoning**
"*The scope of this project is to identify food items in an image and report their nutritional content to the user.*"	**What is the purpose of this product? Who will use it, and for what purpose?**	Experiential observations	Planning	Beneficence
	Who might be harmed?	Experiential observations	Planning	Non-maleficence
"*Images may contain multiple food items. Additionally, the model must be able to determine if the input contains no food items at all.*"	**What are your plans for detecting a wide range of foods with cultural inclusivity?**	Experiential observations	Planning & Describing	Justice
	Who is most influenced by malnutrition? What are the core causes of nutrition problems?	Experiential observations	Planning	Justice
Not mentioned in the report	**How might you store and track all the data created from all the pictures taken in a way that other researchers can use it?**	Future Reasoning	Acquiring & Preserving	Beneficence
"*Our model must work on images taken from typical mobile devices and be able to identify the food within them, even if the images are low quality or off-center. The food in an image should not need to take up the majority of the image in order to be identified.*"	**How will you ensure consistent data output?**	First Principles	Analyzing	Non-maleficence
	How will you deal with data output with private information?	First Principles	Planning, Acquiring & Preserving	Autonomy
"*For classification, we use the Food-101 dataset from Kaggle. It consists of 101 food classes, with each class containing around 1,000 images.*"	**How can you ensure that the dataset used for training incorporates an equal distribution of cultural and international foods?**	First-Principles	Planning & Acquiring	Justice
	What are the trade-offs of the other databases you have considered? For example, ` their range of food types.	Trade-offs	Acquiring	Justice
"*…one of the primary goals for food classification is to increase the consumer's awareness about the food that they are consuming…*"	**Is the algorithm dependent on camera quality?**	Experiential Observations	Acquiring	Justice
	How accessible is this product to those with physical disabilities?	Experiential Observations	Discovering	Justice

"While most of the food images are classified correctly and labeled with relevant food information, some cases exist where the detected food belongs to a class outside the 101 classes of food we have considered."	**What are the reasons for misclassification?**	Experiential Observations	Acquiring, Describing & Analyzing	Non-Maleficence
	How can the dangers of misclassification be mitigated?	First-Principles	Planning	Beneficence
	Could this data be used maliciously?	Future Reasoning	Planning	Beneficence
"*Our project is similar in scope to the TADA Project[25] and has extensive applications in mobile software, diet planning, and healthcare.*"	**Are there any possible copyright infringements? Could this result in legal disagreement?**	First-Principles	Planning & Preserving	Justice

The food classification project above demonstrates the practical application of the Design Reasoning in Data Life-cycle Ethical Management framework by showcasing its potential use in engineering design projects. By posing reasoning questions according to the framework's components, the project addresses not only the technical design requirements but also the essential data and ethical considerations.

Informal design review conversations within engineering design teams provide opportunities to engage with their data or design artifacts using the reasoning questions. These interactions involving peers or mentors (including graduate students, post-docs, and faculty) prompt the necessary reasoning and offer guidance on additional aspects the team should consider during their design process. Therefore, the framework's strength lies in its pedagogical value of empowering students to think holistically about their designs and engage in meaningful discussions with their peers.

In a formal setting, final design presentations, demos, capstone projects, or posters can be evaluated using tools derived from the framework such as the Design review conversation & coaching tool shown in Appendix A. Alongside guidance from mentors to introduce these framework principles, these tools will be provided to students early in the process, outlining the design, data, and ethical reasoning criteria for assessing their work. Students can integrate the necessary reasoning throughout the engineering design process by aligning their designs with the rubric.

One of the ways we intend to measure the framework's effectiveness is by observing how students internalize the provided reasoning questions and integrate them into classroom discussions. By assessing students' use of the framework's principles in their discussions, we can gauge the impact of the framework on their engineering design, data, and ethical reasoning.

The framework's impact will be evaluated and integrated into future iterations through feedback gathered from formal and informal design review conversations between students and their mentors and the analysis of students' technical reports like the example above.

4. Conclusion

Engineering problems are becoming increasingly complex due to growing datasets, sophisticated AI algorithms, and the emergence of complex ethical dilemmas. Therefore, ethical and data reasoning needs to be integrated into engineering design in undergraduate education. This conceptual paper introduces the Design Reasoning in Data Life-cycle Ethical Management framework to support this integration of design, data, and ethical reasoning. This integration can be cognitively demanding because it requires fluently navigating across these three distinct yet essential types of reasoning, which are needed in engineering. The novelty of the framework is in its integration of design and data reasoning with ethical reasoning under the engineering practice of negotiating risks and benefits. In addition to supporting students with this integrated reasoning through formal and informal design review conversations in coaching sessions, the framework guides educators in eliciting and practicing the reasoning with students. For future work, the framework will continue to undergo refinement with feedback from students, design faculty, and researchers to assess and enhance its impact on engineering design in undergraduate education.

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Appendix A: Design review conversation & coaching tool

	Exceptional (5-4); Evolving (3-2); Emerging (1-0)	Score	PRINT ONLY FOR DESIGN REVIEWERS Possible questions to ask during the Interview
Authenticity & Acknowledgment	☐ Shows presence, listens to questions, and responds ☐ Shares enthusiasm, interest in the project ☐ Shares own contributions while crediting others ☐ Recognizes feedback (mentors, users who provided feedback, etc.) ☐ Cites key references/people in support of arguments ☐ ………………………		That is an impressive interesting prototype/concept/title! ▪ Can you tell me about your project? ▪ Who else contributed to ideas presented in this project? ▪ What need/problem is your project addressing?
Transformative Agency	☐ Described the project purpose clearly ☐ Explains benefits of the project and the solution generated ☐ Recognizes users beyond client and other beneficiaries ☐ Demonstrates user empathy ☐ Shows understanding of local circumstances and cultural context ☐ ……………………		You seem to really care about ______. ▪ Can you tell me more, what motivates/ excites/ worries you about this topic? ▪ Who benefits from this solution? ▪ Who might be impacted negatively? ▪ What need/problem is addressed here?
First-principles Reasoning	☐ Explains how the solution works ☐ Explains "why" the solution works (scientific/technical principles) ☐ Presents evidence in support of why solution works ☐ Discusses the performance of prototype with respect to specific design metrics ☐ Uses reasonable, accurate scientific mathematical and or technical concepts units and or data in solutions ☐ ………………………		That is an interesting prototype. ▪ Can you tell me how your solution works? ▪ What are the key theories/principles that guided this idea? ▪ What are examples of evidence that supports your solution? ▪ What are the strengths of your solution?
Data Ethical Reasoning	☐ Explains how data and evidence are gathered ☐ Has a clear understanding of where data are stored, who has access, etc. ☐ Recognizes potential misinterpretations of data ☐ Presents visuals and charts with captions, axis labels, and units ☐ Clearly links to data to inform design decisions ☐ ……………….		I noticed your graph/chart/data visualization. You referred to this visualization. ▪ Can you tell me - how did you obtain/generate the data? ▪ How did you determine that your visualization accurately reflects the data? ▪ Where do you store the data? How do you store? Who has access to these data? ▪ How might this visualization be misinterpreted? How might the data be misused?
Trade-offs Reasoning	☐ Shares limitations of the solution ☐ Explains competing requirements and the trade-offs made to arrive at a final solution ☐ Trade-off consideration considers three or more criteria/constraints ☐ Clearly links metrics to key criteria/constraints ☐ Clearly links metrics to first-principles ☐ ……………		I heard you talk about X metric, how about Y? ▪ What trade-offs did you consider when deciding which method to use? ▪ For example, when you improved X, did this negatively impact Y? ▪ What are the limitations of your solution?
Futures Reasoning	☐ Explains ideal conditions for the success of implementing the solution ☐ Explains consequences if the problem is not addressed ☐ Recognizes potential unintended uses of proposed design ☐ Recognizes those who may be harmed (people, animals, environment) and consequences ☐ Describes necessary changes, documentation, or policies for proper future use ☐ ……………		Let's imagine your solution is selected and is put in use. ▪ How will the solution work in 5 years? ▪ What conditions may prevent the planned benefits of your solution? ▪ In five-years from today, what challenges would be faced? ▪ Can you think of alternative uses or misuses of the design? ▪ Who might be harmed if it is misused? ▪ What policies, procedures, and documentation might be needed?
	TOTAL		