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A SunCam online continuing education course

Ethics for AI in Engineering

by

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Course Outline:

AI Ethics
AI in Engineering
Responsible Charge
Transparency
Bias
Public Welfare
Helpful References
Examination

AI Ethics

Artificial intelligence (AI) is the re-creation of human cognitive functions by artificial means involving computer software. As AI capabilities grow, so does the potential for AI to cause harm. Main areas of concern are as follows:

- AI has biases and spreads misinformation
- AI and its creators are not accountable to mistakes that have consequences
- AI shares personal information and does not respect privacy
- AI stops following human directions and becomes unsafe
- AI becomes conscience
- Military AI tools end up in dangerous hands
- AI benefits a select few and increases inequality
- AI takes jobs and leads to high unemployment
- AI is used for committing crimes
- AI increases energy consumption which harms the environment
- Inadequate or inconstant regulations

These worries generally fall into the realm of "ethics". Ethics is concerned with moral principles and behaviors. Like doing the right thing and considering others before oneself. "AI ethics" promotes the *responsible* development and application of AI. The lofty goal is to guide AI such that it remains fair, safe, secure, and environmentally friendly.

Professional Ethics

Professional ethics are standards of behavior for working professionals. For example, the Hippocratic Oath has been taken by physicians since the fourth century BCE. The oath established several principles of medical ethics still in use around the world, including medical confidentiality and non-maleficence.

Today, professional behavior standards are set and enforced by:

- Employers, such as corporations,
- Professional organizations, and
- Federal, state, or local regulations.

Professional standards directly benefit those receiving professional services. The standards also indirectly benefit professionals who gain the trust of the public and gain protection from other professionals. Behavioral standards keep professionals working on an equal playing field.

Disciplinary consequences (punishments) help ensure practitioners follow the behavior standards. Many behavioral standards are covered by an employer, professional organization, and in regulations. Thus, breaking a standard can result in consequences from multiple entities.

Engineering Ethics

Engineering is one of the main professional fields. As such, there are several behavioral standards specific to engineers. In the United States, the main document is the “Code of Ethics for Engineers” by the National Society of Professional Engineers (NSPE). The Code lists six fundamental canons:

NSPE® NATIONAL SOCIETY OF PROFESSIONAL ENGINEERS

Code of Ethics for Engineers

I. Fundamental Canons

Engineers, in the fulfillment of their professional duties, shall:

1. Hold paramount the safety, health, and welfare of the public.
2. Perform services only in areas of their competence.
3. Issue public statements only in an objective and truthful manner.
4. Act for each employer or client as faithful agents or trustees.
5. Avoid deceptive acts.
6. Conduct themselves honorably, responsibly, ethically, and lawfully so as to enhance the honor, reputation, and usefulness of the profession.

AI Impact to Canons

Table 1 lists examples of how the use of AI can help achieve or risk deviating from each of the six fundamental canons in the NSPE Code of Ethics.

Table 1: Examples of AI Usage Impacting NSPE Canon Compliance			
No.	**Fundamental Canon**	**AI Helps Comply**	**AI Risks Deviating**
1	Hold paramount the safety, health, and welfare of the public.	AI detects and prevents dangerous failures. AI solves complex technical problems and generates solutions that help society achieve sustainability.	AI presents a solution that is not reviewed and is implemented with mistakes that create unsafe conditions.
2	Perform services only in areas of their competence.	AI is a tool for design tasks within the discipline of the engineer of record.	AI is used to design improvements outside the discipline of the engineer of record, resulting in unusable features and code noncompliance.
3	Issue public statements only in an objective and truthful manner.	A report is reviewed by an AI-based grammar check, which suggests clearer and grammatically correct sentences for presenting important concepts.	An AI large language model is used to create a report which includes biases and unsupported conclusions. The engineer is too busy to verify the information.
4	Act for each employer or client as faithful agents or trustees.	AI performs iterations to arrive at a solution very quickly, allowing the design engineer to complete the work within the timeline required by the client.	AI software uses confidential and proprietary design details from a past project to generate a design for a new client.
5	Avoid deceptive acts.	An engineering firm checks all reports for potential plagiarism with an AI-based software.	A 3D modeling software uses generative AI code, but the software specifications state it is not AI software.
6	Conduct themselves honorably, responsibly, ethically, and lawfully so as to enhance the honor, reputation, and usefulness of the profession.	An XAI design program is developed with transparency on all design decisions and the ability to view and print all calculations performed.	An engineer neglects to account for an important design condition and blames the AI software for the miss.

NSPE AI Statement

In September 2023, the NSPE published Position Statement No. 03-1774 on Artificial Intelligence. That documents states that by upholding ethical standards, Professional Engineers play a pivotal role in ensuring AI benefits society while minimizing its risks. The statement focuses on these seven areas:

1. Ethical Responsibility:
   AI technologies should be designed and used in ways that do not harm individuals, society, or the environment.

2. Safety and Reliability:
   NSPE advocates for verification, validation, testing, and continuous monitoring of AI systems used in engineering applications. Engineers should apply their expertise to establish robust safety standards for AI applications.

3. Professional Licensure:
   Individuals who design AI systems should be held to the same standards as professional engineering licensure. Licensing of engineers ensures that those engineers working on AI systems possess the necessary qualifications, experience, commitment, and accountability to uphold the public's well-being.

4. Transparency and Accountability:
   AI systems should be designed to be transparent, so users can see how decisions are made, and accountable, so there are consequences for developers and users when mistakes are made the impact public welfare.

5. Privacy Protection:
   Engineers and AI professionals should respect privacy laws and best practices.

6. Continuous Education and Training:
   NSPE promotes continuous education and training for engineers and AI professionals to stay current with advancements in AI technology and ethics.

7. Collaboration and Interdisciplinary Approach:
   NSPE advocates for collaboration among engineers, data scientists, ethicists, policymakers, and other stakeholders to address the complex challenges posed by AI.

AI in Engineering

AI software for technology and design applications is developing rapidly. A good portion of existing software programs now have aspects of AI built-in, often as toolkits or optional add-ons. And many new software programs with AI have been released for commercial sale since around 2020.

AI can help engineers during design by:

- Gathering and analyzing reference information,
- Generating design ideas and alternatives,
- Optimizing parameters and complex combinations,
- Creating more efficient designs,
- Designing more quickly than a human,
- Creating layouts and 3D models,
- Programming design tools, and
- Quality reviews of designs.

Equipment and control systems specified by engineers can have "smart" features included, which commonly indicates an aspect of AI. Although the specifying engineer may not personally use the program, it is important for the engineer to understand how the AI program functions and its limitations, especially if safety could be comprised.

AI Algorithms

Traditional computer programs complete functions based on inputs and comprehensive rules (such as logic and formulas) provided by a subject matter expert and entered by a programmer or developer. The same input produces the same output every time.

AI based programs don't need all the rules to be defined since AI algorithms can utilize input data and training to determine the rules (step 1), and then apply the rules to new situations (step 2). The programmer does not need to consider all potential scenarios nor be an expert in the subject matter. The same input may produce different results over time as the program learns from previous mistakes and from new information.

See Figure 1 for a comparison of a traditional algorithm and an AI-based algorithm.

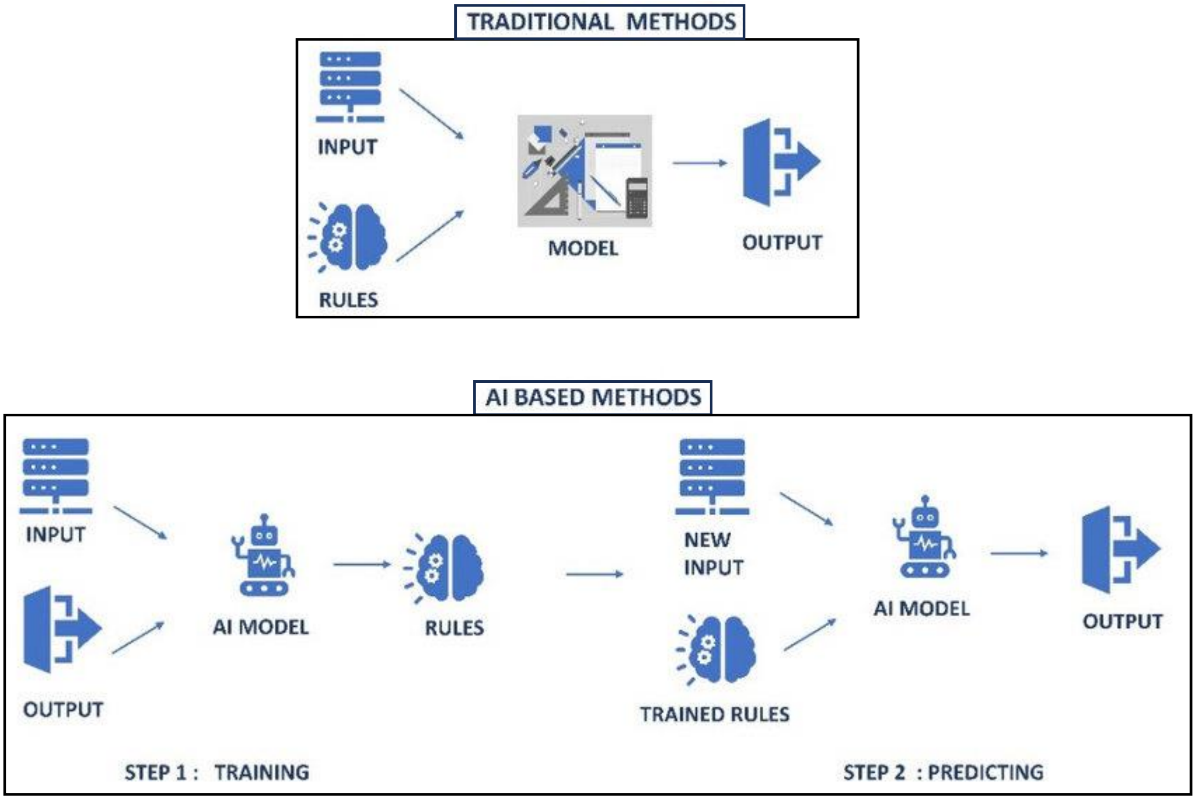

Figure 1: Top) Traditional algorithm.
Bottom) AI-based algorithm that analyzes initial data to find patterns and create rules (step 1: training). These rules are applied to new inputs to provide solutions (step 2).
Source: https://ui.adsabs.harvard.edu/abs/2022RemS...14.3377K/abstract, CC-4.0

Neural Networks

A neural network is a form of AI that is inspired by the human brain. Neural networks are also known as simulated neural networks (SNNs) or artificial neural networks (ANNs). Neural networks involve applying weights to inputs to help determine the most important factors in solving a problem. Iterations can also be included to optimize the results. It is important to understand that neural networks need to be trained with existing information and example problems prior to being used on new applications.

AI Categories

Table 2 provides an overview of common categories (or forms) of AI. New categories are likely to emerge as AI is further developed for vastly different applications.

Table 2: Categories of AI Systems

Category	Intelligence	Learning	Rules	Examples	Notes
Expert Systems	Limited or None	None or Limited	Fixed	KBES, Fuzzy Logic, Diagnostics	Built for specific tasks, AI features are optional
Machine Learning	Cognitive	Supervised, Unsupervised or Reinforced	Self-modified	Deep Blue, Voice-to-Text	Algorithms can learn from new data
Large Language Models	Cognitive	Supervised, Unsupervised or Reinforced	Self-modified	ChatGPT, Chatbots, Search Engines	Perform natural language processing (NLP) tasks, large data
Deep Learning	Cognitive	Neural Network	Self-modified	Autonomous Vehicles, Python, Facial Recognition	Advanced type of machine learning, complex decision-making abilities
Generative AI	Cognitive	Various	Self-modified	Generative Adversarial Networks, Variational Autoencoders	Design examples: structural optimization, shape synthesis
Strong AI	Cognitive & Emotional	Independent	Self-created	None (Theoretical)	Creative abilities, optical computing
Super AI	Cognitive, Emotional, & Social	Superior to Human Learning	Not Required	None (Theoretical)	Self-aware, beyond most human abilities, artistic creativity

Deep Learning

Deep learning has several engineering applications, including autonomous vehicles as shown in Figure 2. Deep learning can process vast amounts of data, often in real-time, and make complex decisions.

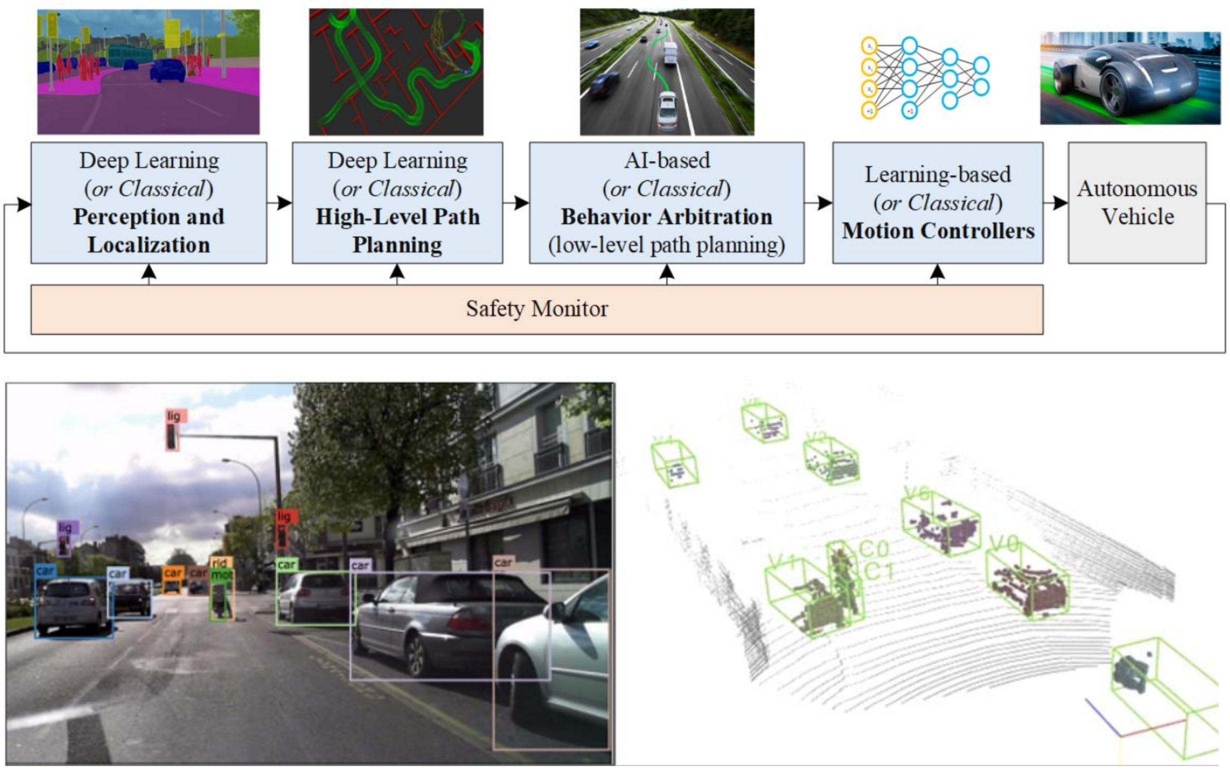

Figure 2: Top: Architecture for self-driving cars with deep learning.
Bottom left: Scene detection with 2D images from bumper.
Bottom right: Scene detection with 3D data from LiDAR on the roof.
Source: https://arxiv.org/pdf/1910.07738, Grigorescu et. al.

<u>Gen AI</u>

Generative AI (Gen AI) is a popular add-on to existing engineering software. Gen AI can generate (create) new ideas, models, and drawings. For example, structural engineering programs, such as STAAB, now have Gen AI tools that can help develop new models, optimize parameters, and simulate operating conditions. See Figure 3 for how Gen AI is considered subset of Deep Learning which is a subset of Machine Learning.

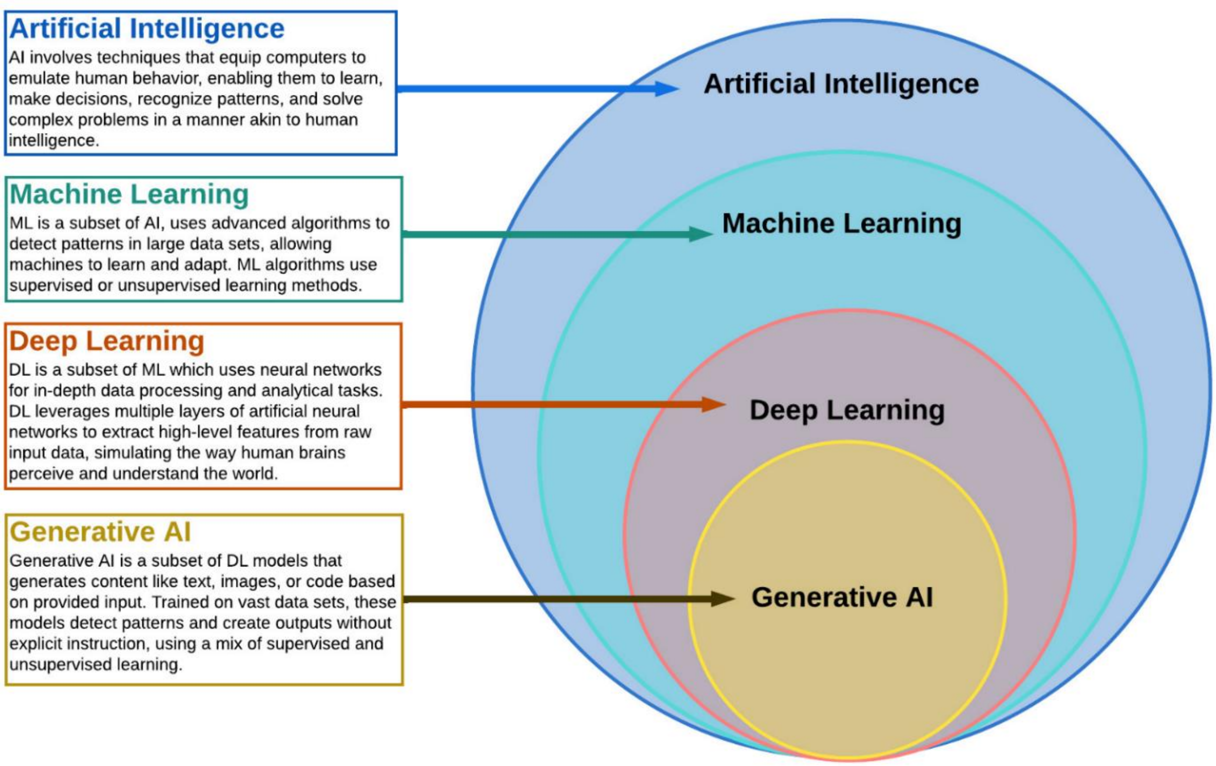

Figure 3: Venn diagram with Generative AI.

AI Tools
The following are popular AI tools related to engineering.

Predictive Maintenance	
Description	**Examples**
• Predictive maintenance (PdM) uses AI algorithms to predict failure or detect the first signs of failure of physical parts such as machines or electrical parts. • Early detection allows maintenance or replacement prior to a costly failure. • Predictive maintenance uses data analysis to continuously monitor operating conditions and working environments to detect early clues for degradation of equipment.	• Accruent • IBM Maximo® Predict, • InfluxData, Fiix • Limble CMMS, • LLumin, MaintainX, • MATLAB, UpKeep, • Reftab, Samsara, • Siemens MindSphere

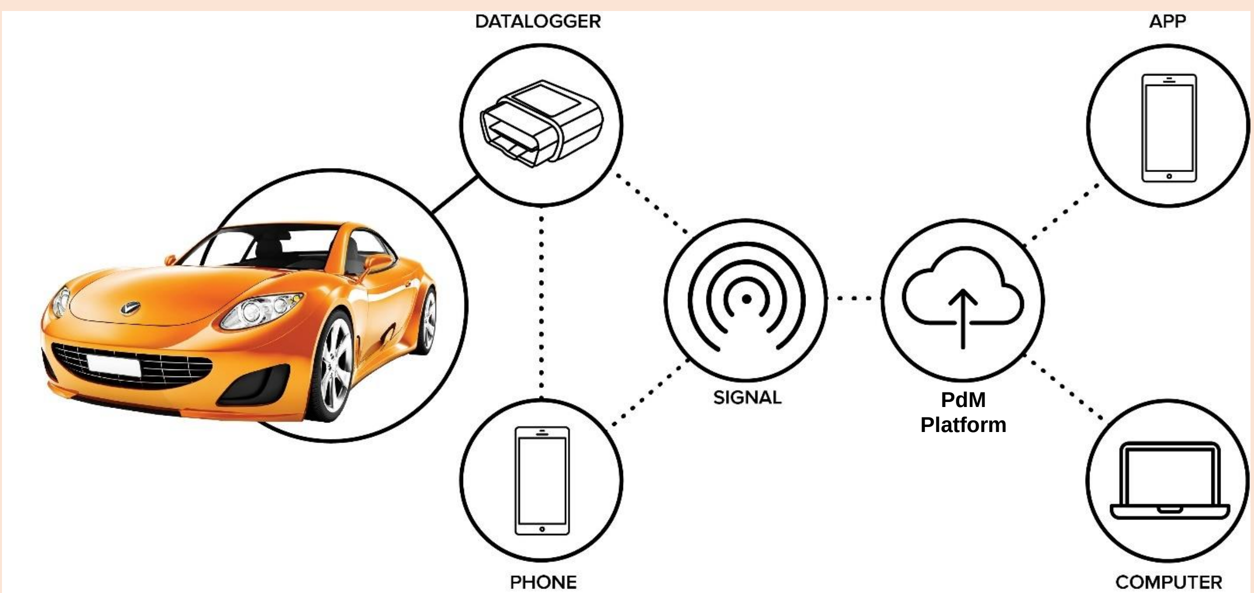

Figure 4: Communication paths for automobile preventative maintenance (PdM).
Source: commons.wikimedia.org/wiki/File:DataLogger_Platform-_How_it_Works.jpg, Danlaw Inc

Digital Twins	
Description	**Examples**
• A digital twin is a model of a physical system with a boost of AI and real operating conditions to help simulate dynamic real-world scenarios. • Uses both deep learning and generative AI. • Digital twins are built using the current asset condition and relevant historical data about the asset. • Digital twins can be used to optimize the current condition, optimize operations and maintenance, and predict future behaviors. • The models can reflect ongoing operations by direct streaming of data into the AI algorithms.	• Example applications include machinery, engines, pumps, production equipment, assembly lines, packaging systems, power plants, or an entire fleet of vehicles. • Bentley's iTwin

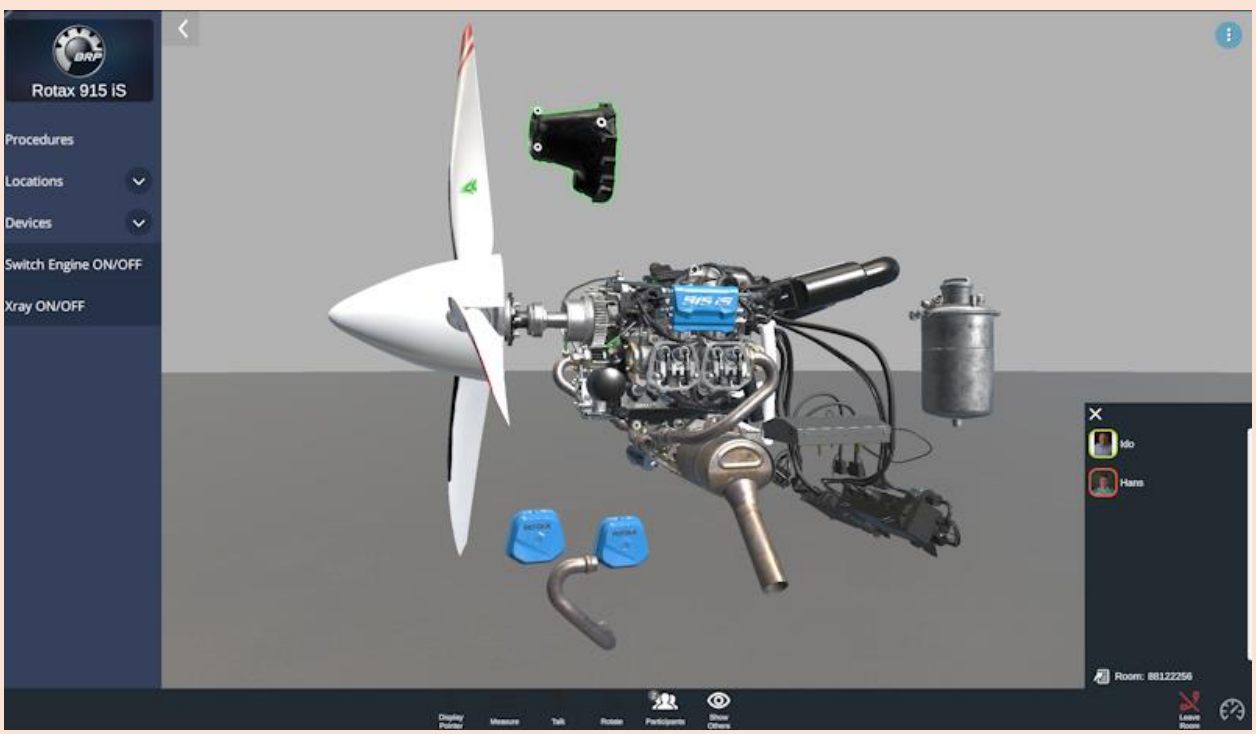

Figure 5: Example digital twin model of a propeller engine.
Source: commons.wikimedia.org/wiki/File:Training_with_digital_twin.jpg, Iditsulkin, CC-BY-SA-4.0

Virtual Assistants	
Description	**Examples**
• Virtual assistant (VA) is a large language model (LLM) that interacts in a human-like manner. • Can perform a range of tasks or services based on user input such as commands or questions. • Typically utilizes online chat (chatbot) capabilities to simulate human conversation. This is also called a visual dialog model. • Some virtual assistants can interpret human speech and respond via synthesized voice. • Can assist engineers in finding information and making informed decisions.	• Apple's Siri • Apple Intelligence • Amazon Alexa • Google Assistant / Gemini • Microsoft Copilot • Mycroft (open source) • Samsung's Bixby • Slackbot

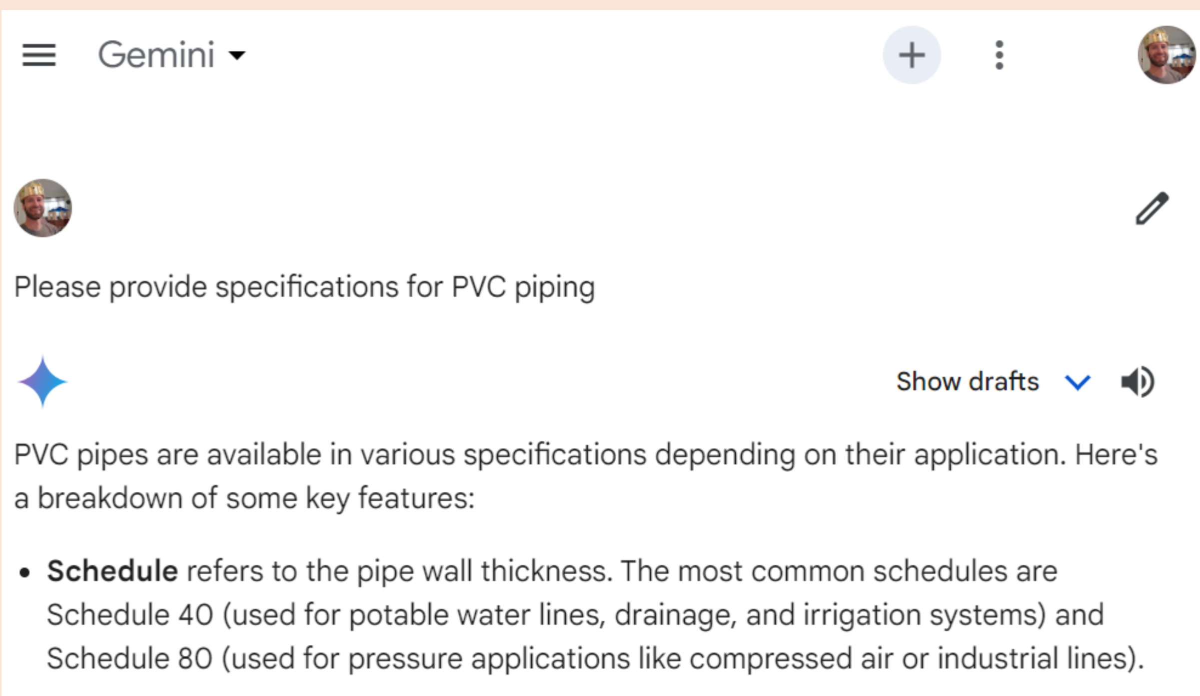

Figure 6: Example of an AI chatbot providing engineering information.
The source of the information should be confirmed before project use.
Source: commons.wikimedia.org/wiki/File:Visual-Dialog.png, Abhishek Das, CC-BY-SA-4

Smart Infrastructure	
Description	**Examples**
• IoT (Internet of Things) devices linked to a central system with AI for real-time monitoring and control. • Instrumentation and controls systems can become "smarter" with the addition of deep learning or Gen AI. • AI can review trends, monitor current conditions and make adjustments to achieve energy efficiency or other goals. • Some systems sold with label "smart" do not actually have AI programming.	• Utilities infrastructure (water meters, electric meters, monitoring, etc.) • HVAC controls • Security systems • Surveillance systems • Smart home system

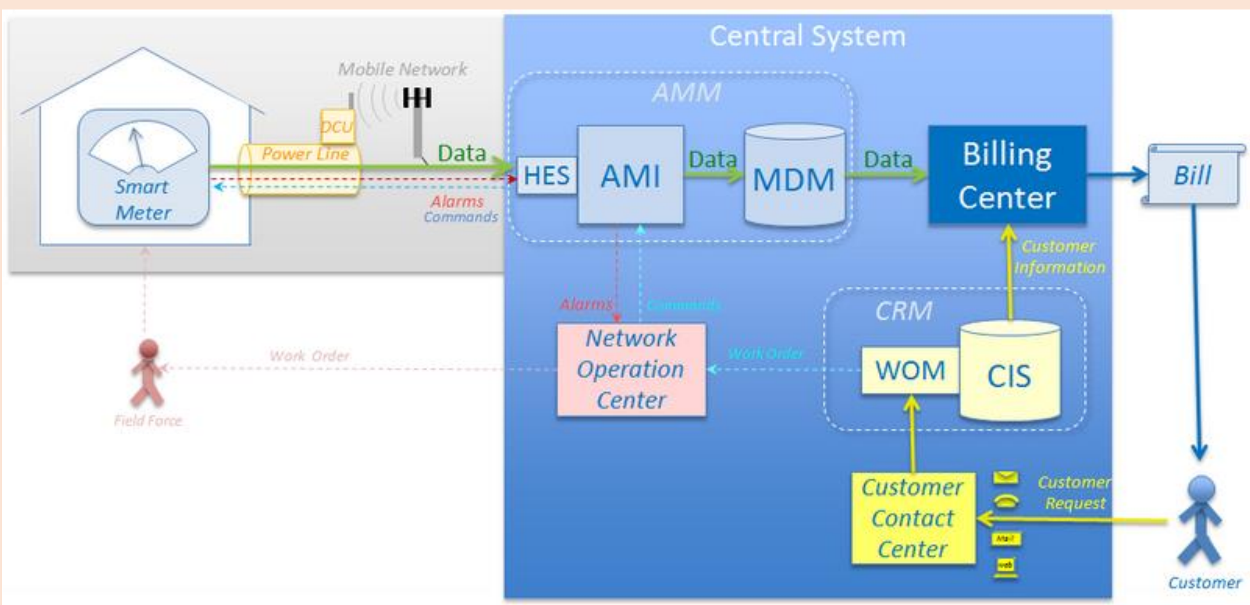

Figure 7: Smart meter system for billing customers.
AMM = Advanced Meter Management (software and hardware bundle)
HES = Head End System (sends and receives smart meters signals)
AMI = Advanced Metering Infrastructure (controls the smart meters, AI potential)
MDM = Meter Data Management (data storage & calculations, AI potential)
Source: commons.wikimedia.org/wiki/File:Smart_Meter_Infrastructure.png, Skyhead, CC-BY-SA-4

Hardware-based AI	
Description	**Examples**
• Hardware-based AI is specifically designed to operate physical components. • Collaborative robots, called cobots, are becoming common in the workplace, working alongside humans in various applications, especially where physical items are being manufactured. • Robots excel in tasks that require high levels of precision, speed, and consistency. • Robotic systems are also equipped with advanced sensors and AI algorithms, enabling them to adapt to their human counterparts' actions and learn from their experiences. • AI programming allows robots to learn and thus become more reliable and efficient with time.	• Autonomous vehicles • Drones • Robots (Cobots, Delta, Educational, Humanoid, Industrial, etc.)

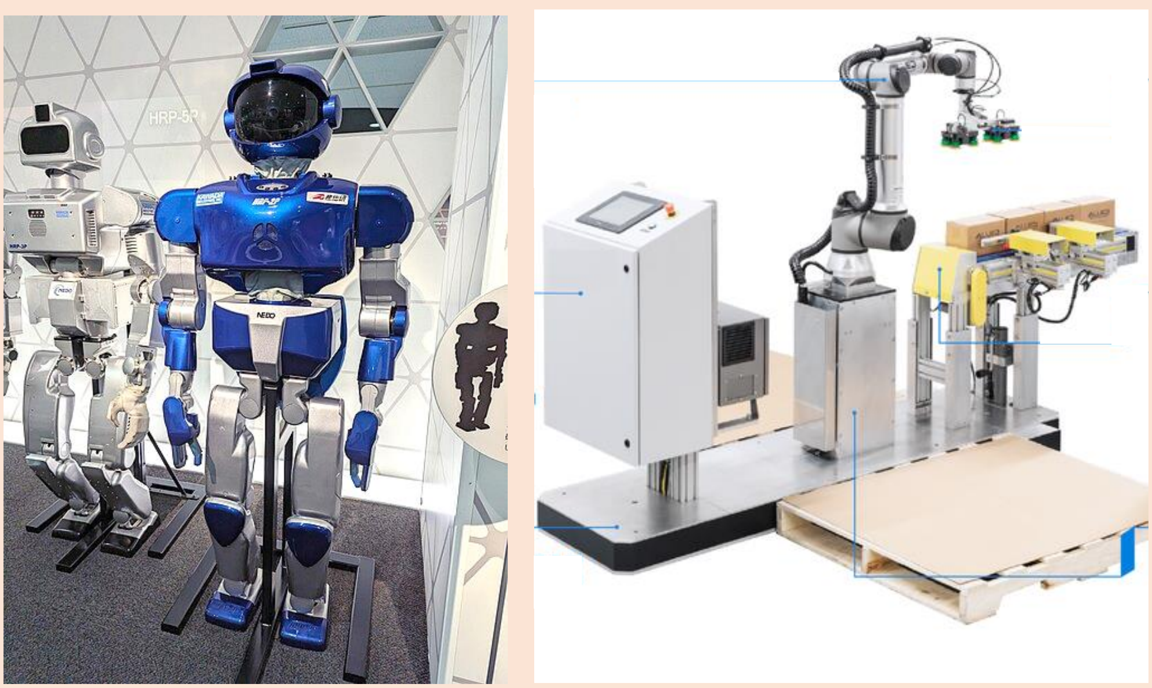

Figure 8: left) humanoid robots; right) industrial packaging cobot.

Responsible Charge

For most engineering design work, there must be a licensed engineer with "responsible charge" of the work. For projects that enter a construction phase, the term engineer of record (EOR) is often used. The EOR is to maintain "responsible charge" of the design when AI is being utilized to help complete design work. Other engineers or designers can work under the direction of the EOR.

The following two guiding documents provide the most accepted context and definition for the "responsible charge" requirement. Many states and local jurisdictions have additional requirements.

National Council of Examiners for Engineering and Surveying (NCEES) Model Law

- Licensed engineers shall be in **responsible charge** of all engineering design of buildings, structures, products, machines, processes, and systems that can affect the health, safety, and welfare of the public
- Any jurisdiction, county, or local government agencies or authorities, or officials or employees thereof, shall not engage in the practice of engineering or surveying involving either public or private property without the project being under the **responsible charge** of a professional engineer for engineering projects
- The term "**Responsible Charge**," as used in this Act, shall mean direct control and personal supervision of engineering work

NSPE Position Statement No. 10-1778

- Defines "Responsible Charge" as the direct control and personal supervision of engineering work.
- The professional engineer in **Responsible Charge** is actively engaged in the engineering process, from conception to completion.
- Engineering decisions must be personally made by the professional engineer or by others over which the professional engineer provides supervisory direction and control authority.
- Reviewing drawings or documents after preparation without involvement in the design and development process does not satisfy the definition of **Responsible Charge**.

Direct Control
"Direct control" or "control authority" implies the ability to give direction and have the "final say" in engineering decisions. This includes the authority to decide whether or not to use AI for each design project.

Approaches to maintain direct control when using AI:

- Make design decisions and adjust the design accordingly, either within the AI software or after exporting the AI results, but prior to producing final drawings, specifications, and calculations.
- Use XAI software to review AI decision making and determine if acceptable.
- Do not sign and seal drawings from a program that produces drawings in a single step. There should be multiple design steps, or stage gates, so an engineer can review design progress, make decisions, give directions, or manually modify the design prior to creating a final design and drawings.
- Ensure the AI program follows directions given.
- Document directions given and design decisions made.

Personal Supervision
"Personal Supervision" or "supervisory direction" means to observe the design work, be actively engaged throughout the design, review any work done by others, and guide the work of others.

Approaches to maintain personal supervision when using AI:

- Understand how the AI program works such as by reading the software user manual, completing the tutorial, or being trained in its use.
- Consider the AI program reputation, history, and experience related to the engineering tasks. Can it be trusted for this application?
- Review the inputs and outputs of the AI program, using XAI when possible.
- Review calculations performed by AI. If the AI program involved many iterations, at least review the calculations for the final design result. In cases such as finite element analysis (FEA) or computational fluid dynamics (CFD), review of the calculations at each node may not be practical as there are often millions of nodes in a model. However, key parameters and results should be reviewed in depth such that the engineer is satisfied with the accuracy and confident in the overall design.
- Save the inputs, outputs, and calculations in an accessible format such as pdf.

Example Problem 1

Engineer Floyd is the licensed engineer in responsible charge of the electrical design of a medical complex expansion. Floyd took a month off work to care for his newborn daughter and has now returned to work. The medical complex project has advanced from preliminary design to final design with drawings due to the client in 3 weeks. Floyd takes the following steps to get the electrical design back on track. Which steps are primarily direct control versus personal supervision?

1. Floyd attends a design workshop.
2. Decides on an AI program for lighting design and photometrics.
3. Collaborates with the architect on the electrical room size and door locations.
4. Makes red-line markups of drawings with final decisions.
5. Discusses standby power alternatives with the client.
6. Client asks if an existing MCC from 1980 can be reused. Floyd determines it doesn't meet code requirements and informs client that a new MCC is needed.
7. Asks a subordinate engineer-in-training to size conduits and conductors for Floyd's review.

Solution:

Although some activities fall into both categories, the following colors show the **primary** category with **direct control in red** and **personal supervision in blue**.

1. Floyd attends a design workshop.
2. Decides on an AI program for lighting design and photometrics.
3. Collaborates with the architect on the electrical room size and door locations.
4. Makes red-line markups of drawings with final decisions.
5. Discusses standby power alternatives with the client.
6. Client asks if an existing MCC from 1980 can be reused. Floyd determines it doesn't meet code requirements and informs client that a new MCC is needed.
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Transparency

One of the biggest concerns with the use of AI in engineering is a lack of transparency. The main concern is that an AI program can make important engineering decisions without the licensed engineer understanding what has been done, thereby increasing risks and leaving the engineer not truly in responsible charge of the work.

The NSPE Position Statement No. 03-1774 specifically discusses “transparency” as a major AI ethical concern. The NSPE promotes transparency in AI algorithms and data, enabling users to understand how decisions are made.

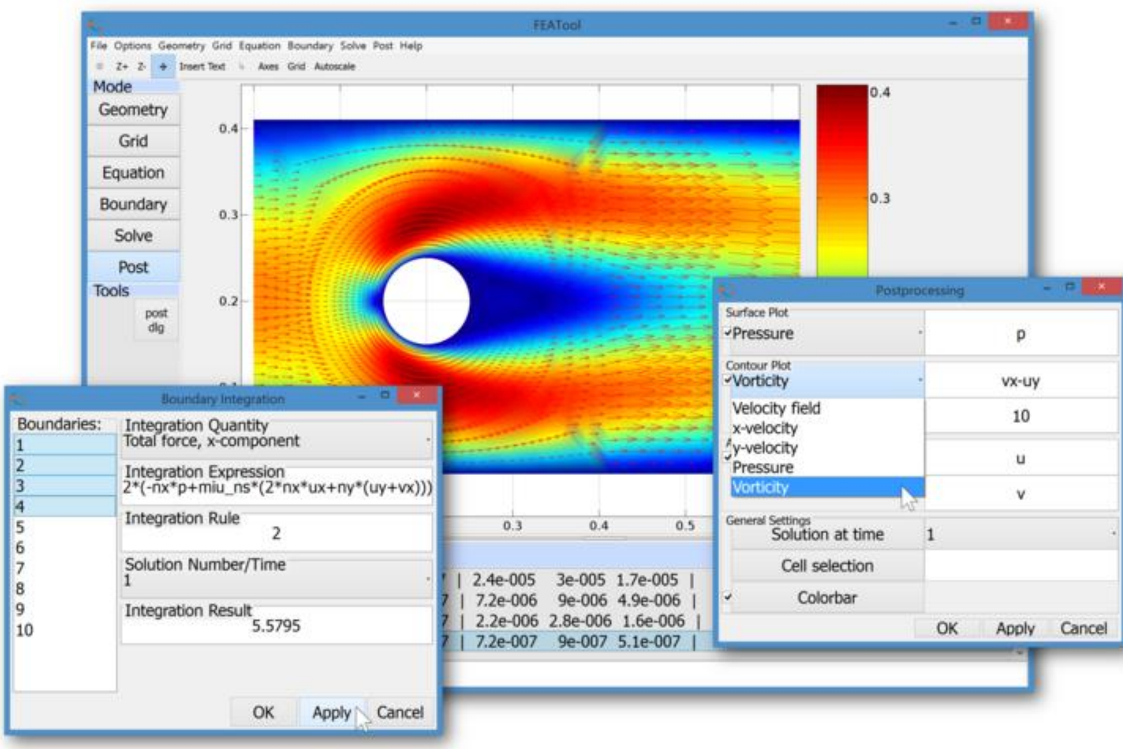

Figure 9: Example CFD program with interface windows
to allow exploring inputs, equations utilized, and results.

Source: commons.wikimedia.org/wiki/File:Featool-multiphysics-matlab-fem-and-cfd-gui-toolbox.png, Precise Simulation Ltd.

XAI
One approach is to qualify programs that have sufficient transparency as Explainable Artificial Intelligence (XAI). To qualify as XAI, a program must do the following:

- Clearly explain design decisions and actions taken.
- Reveal model results in an accessible format such as pdf.
- Provide instructions, training, and help menus, including explaining the types of AI algorithms and any data sources utilized.
- Utilizes modified machine learning techniques that produce more explainable models such as graphical interfaces.
- Allows a user to modify the design or re-run the program based on new inputs or directions.

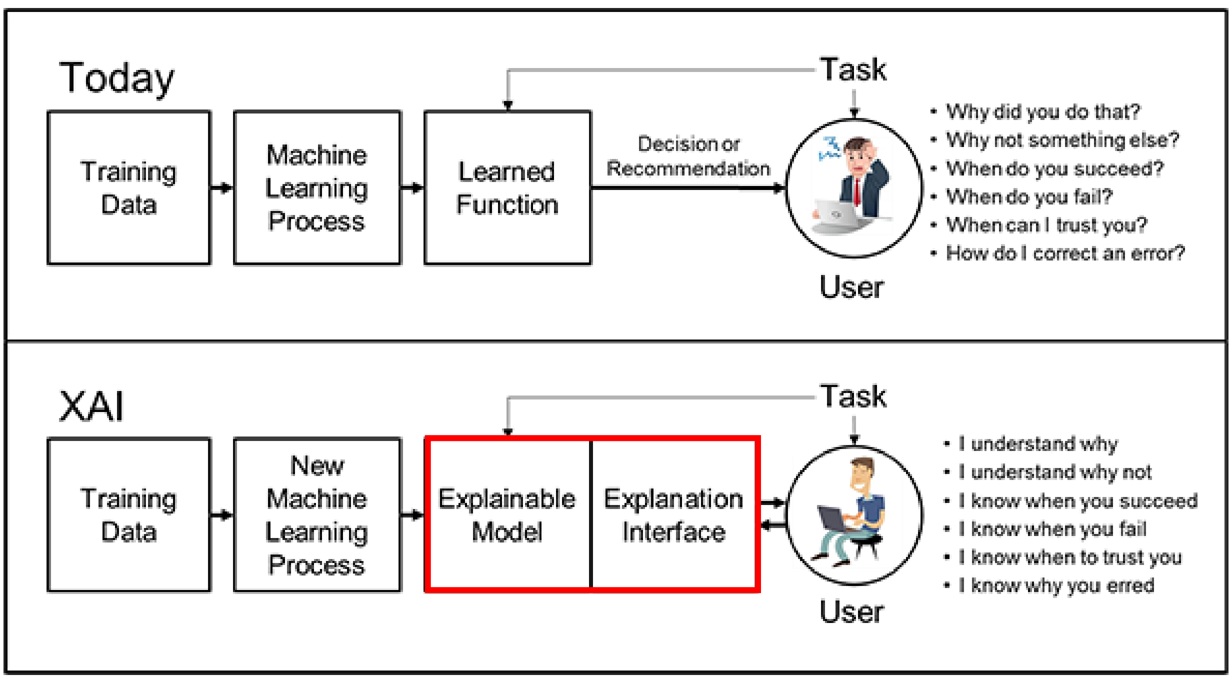

Figure 10: Normal AI (top) versus XAI (bottom) with key differences in **red**.
Source: www.darpa.mil/program/explainable-artificial-intelligence, public domain

XAI examples include:

- Financial Services: Paypal, ZestFinance, BlackRock
- Healthcare: IBM Watson, Google DeepMind, PathAI
- Legal: SpeedLegal, Goldman Sachs
- DARPA XAI program

Bias

AI bias is an intensely debated ethical issue. For example, there are major concerns that large language models have and continue to show biases for gender, race, and skin color with image generators, facial analysis, language translations, and medical diagnosis. This is common when the AI algorithm uses source data that has stereotypes or is not sufficiently diverse. Bias can also happen when the AI programmers are not diverse or do not expose the AI program to a broad range of views or data.

Similarly, bias can be present in engineering software which produces only a narrow range of solutions when many more options are available. Potential sources for bias in Gen AI engineering software include:

- Program trained on limited data or limited example problems.
- Experts used in software development did not consider other techniques, formulas, or approaches, either due to ignorance, personal preferences, or limited scope and budget.
- Program does not have access to new data or has not been updated.
- Program oversimplifies a complex topic.
- Program designed for limited, straightforward applications but doesn't declare the limitations.
- Program uses excessive assumptions when modeling physical phenomena and thus is not accurate.
- Inputs are limited, resulting in few design options and limited results.

Bias can also be present in engineering design work done by hand. Engineers tend to trust what they've learned and what has worked for them, thereby limiting the options considered. There is also a financial and schedule benefit to modifying a previous design rather than starting from scratch with new concepts and approaches. Thus, engineers tend to become specialists in particular solutions and carry a bias towards those solutions.

Figure 11: Example of two houses designed by the same consultant team. Engineers often copy from previous designs which can be a source of bias.
Source: www.google.com/maps/@43.0954006,-89.2770411 (July 2024)

AI has the potential to break biases and help develop fresh design alternatives that are specific to the application. In this way, AI can be seen as a path towards less bias and potentially more safe and reliable design solutions.

Public Welfare

Ethical concerns for using AI grow when there is a potential impact to the safety, health, or welfare of the public, which must be held paramount per the Fundamental Canon No. 1 of the NSPE Code of Ethics. NSPE states that robust safety standards be developed for AI software, particularly in critical domains such as healthcare, transportation, and infrastructure. This responsibility lies with both those developing the software and engineers using the software for projects.

Most engineering designs have potential safety impacts, although the risk level varies greatly. Licensed engineers should consider the level of potential harm for each project. The following examples show increasing levels of safety risks:

- Wiring design for lighting of a billboard sign, with potential for electric shock.
- Wiring design for exit signs, with potential for electric shock and potential for not functioning to guide people to an exit during an emergency.
- Wiring design for an emergency surgery rooms, with potential for electric shock, for guiding people during an emergency, and for cutting off power to critical surgeries that could result in loss of life.

If using AI in a high-risk application, consider the following approaches:

- Assess if the AI program can be trusted for the application based on reputation, history, and relevant experience.
- Evaluate if the AI program has sufficient transparency.
- Evaluate if the AI program has biases and if they can be avoided.
- Understand how the AI program works such as by reading the software user manual, completing the tutorial, or being trained in its use.
- Stay in control of design decisions and adjust the design for increased safety.
- Document directions given and design decisions made with AI assistance.
- Create a risk register and update it often.
- Carefully review inputs, calculations, and outputs to the AI program.
- Save the inputs, outputs, and calculations in an accessible format such as pdf.

Risk Register
A risk register is a table with a list of identified risks to a project or process. Normally, there are columns for the following, at minimum:

- Risk ID
- Date Added
- Risk Description
- Probability (aka likelihood)
- Severity (aka impact or consequence)
- Ranking (aka priority)
- Response
- Status

See Table 3 for an example with safety related risks. Some AI software can analyze and identify safety risks, but it is still up to the engineer in responsible charge to consider the safety consequences of the design.

Table 3: Example Risk Register

ID	Risk Description	Probability	Impact	Priority	Response	Status
1	Trip hazard from openings in grating	Medium	Low	Low	Add note to drawings and specifications	Complete
2	Inadequate clearance between equipment	Medium	Low	Low	Add space and adjust room dimensions	In Drafting
3	Truck turn radius too tight	Medium	Medium	Medium	Increase radius and adjust grading	Not Started
4	Safety shower not visible	Low	High	Medium	Move shower and water supply line	Complete

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