DALL-E in a Chemical Engineering Process Design Course

## Downloads

* [Download as Word Document (DOCX)](/downloads/teaching/chemical-engineering-dalle.docx)

# Case Study: Using DALL-E for Visual Learning in Chemical Engineering

## Course Context

**Course:** Chemical Process Safety (ChE 4185)
**Level:** Senior
**Enrollment:** 42 students
**Prior Format:** Lecture-based with case studies and hazard analysis exercises
**Tools:** Process simulation software, hazard analysis templates
**Faculty:** Dr. P, Associate Professor of Chemical Engineering

## Implementation Challenge

Dr. P identified several challenges in her chemical process safety course that AI-generated imagery could potentially address:

1. **Hazard Visualization:** Difficulty helping students visualize complex hazard scenarios
2. **Industrial Context:** Limited exposure to diverse chemical plant environments
3. **Safety Concept Abstraction:** Students struggling to grasp abstract safety concepts
4. **Risk Communication:** Need for effective visual communication of safety information
5. **Engagement with Technical Content:** Traditional textbook illustrations not engaging modern students

## Implementation Goals

The integration of DALL-E (OpenAI’s image generation AI) aimed to:

1. Create customized visual learning materials for chemical process safety
2. Help students visualize hazard scenarios in diverse industrial contexts
3. Develop students’ ability to communicate safety concepts visually
4. Enhance engagement with technical safety content
5. Teach critical evaluation of AI-generated technical imagery

## Implementation Process

### Phase 1: Faculty Preparation (2 months before semester)

1. **Tool Exploration:**
	* Experimented with DALL-E 3 through ChatGPT Plus
	* Developed effective prompting strategies for chemical engineering imagery
	* Tested accuracy limitations for technical processes and equipment
	* Cataloged successful approaches for different safety concepts
	* Created evaluation framework for technical accuracy
2. **Content Development:**
	* Created image series for high-priority safety concepts
	* Developed before/after hazard scenario visuals
	* Generated comparative imagery of safety systems across industries
	* Created visual decision trees for emergency response
	* Designed visual aids for hazard and operability studies (HAZOP)
3. **Integration Planning:**
	* Identified specific lectures for enhanced visual content
	* Developed student activities using AI-generated imagery
	* Created assessment approach for visual safety communication
	* Designed prompt engineering guidelines for chemical engineering contexts
	* Established ethical guidelines for AI image generation and use

### Phase 2: Initial Implementation (First three weeks)

1. **Introduction to Visual Safety Communication:**
	* Demonstrated the power of visual communication in process safety
	* Introduced AI-generated imagery as a safety communication tool
	* Discussed limitations and ethical considerations
	* Showed examples of accurate vs. misleading technical imagery
	* Explained evaluation criteria for technical visuals
2. **Guided Exploration Activity:**
	* Students analyzed pre-generated safety scenario images
	* Small groups identified hazards visible in the imagery
	* Comparative analysis of traditional diagrams vs. AI-generated visuals
	* Discussion of how visual elements communicate risk
	* Practice evaluating technical accuracy of process equipment depictions
3. **Prompt Engineering Workshop:**
	* Taught specialized prompting techniques for chemical process equipment
	* Conducted step-by-step demonstration of iterative prompt refinement
	* Provided chemical engineering-specific terminology guidance
	* Practiced creating technically accurate prompts in small groups
	* Discussed limitations and verification requirements

### Phase 3: Progressive Integration (Throughout semester)

1. **Visual Case Study Enhancement:**
	* Traditional case studies supplemented with AI-generated scenario visuals
	* Students compared textual descriptions with visual representations
	* Discussions about what visuals reveal that text alone might miss
	* Analysis of how visual elements influence risk perception
	* Practice identifying safety systems and failures in visual scenarios
2. **Student-Generated Visual Communications:**
	* Students created their own DALL-E prompts for assigned safety scenarios
	* Iterative refinement based on technical accuracy feedback
	* Peer review of imagery for engineering accuracy and safety communication
	* Development of multi-image sequences showing accident progression
	* Creation of visual safety briefings for specific chemical processes
3. **Integration with Hazard Analysis:**
	* HAZOP studies enhanced with visual representations of deviation scenarios
	* Layer of Protection Analysis (LOPA) diagrams generated to show safeguards
	* Fault tree analysis visually enhanced with AI-generated imagery
	* Emergency response scenarios visualized for training discussions
	* Comparison of AI-visualized vs. traditional hazard communication approaches

## Implementation Examples

### Example 1: From Text to Visual - Hazard Scenario Visualization

**Traditional Approach:** Students read textual case study descriptions and tried to mentally visualize complex accident scenarios.

**DALL-E-Enhanced Approach:** Dr. P created a progression of images showing the development of a runaway reaction scenario in a batch reactor, with each stage visualized to help students understand the sequence of events.

**Example Prompt Evolution:**

Initial Prompt:
"Chemical reactor explosion"

Refined Prompt:
"A sequence showing the stages of a runaway reaction in a jacketed batch reactor in a chemical plant. Start with normal operation, then show signs of cooling system failure, pressure buildup, relief valve activation, and finally containment failure with reactive material release. Show proper industrial setting with realistic equipment, operators, and safety systems. Chemical engineering technical accuracy is essential."

**Learning Application:** Students analyzed the visual sequence to: 1. Identify early warning signs visible in the imagery 2. Note which safety systems were present/absent 3. Discuss how the scenario might differ with additional safeguards 4. Connect visual cues to process safety concepts 5. Develop their own narrative explaining the incident causes

### Example 2: Visual Safety Communication Project

**Assignment Description:** > For your mid-term project, you will develop a visual safety communication package for the assigned chemical process. Using DALL-E, create a series of 5-7 images that effectively communicate: > > 1. The normal operating conditions and key process equipment > 2. Critical potential hazards specific to this process > 3. Proper safety systems and protective measures > 4. Emergency response procedures > 5. Lessons from a historical incident involving this process > > For each image, document your prompt engineering process, including initial prompts, refinements, and technical accuracy evaluations. Prepare a 10-minute presentation explaining how your visual package communicates essential safety information.

**Student Workflow:** 1. Research assigned chemical process and historical incidents 2. Draft initial prompts focusing on technical accuracy 3. Generate and evaluate preliminary images 4. Refine prompts based on feedback and technical review 5. Evaluate final imagery for engineering accuracy 6. Develop accompanying explanatory text 7. Present visual safety package to class

**Evaluation Rubric Excerpt:** - Technical accuracy of chemical equipment and processes (30%) - Effectiveness in communicating safety concepts visually (25%) - Quality of prompt engineering and refinement process (20%) - Critical evaluation of AI-generated imagery limitations (15%) - Integration with process safety principles (10%)

### Example 3: Comparative Hazard Analysis

**Traditional Approach:** Students completed HAZOP worksheets using text descriptions and generic process diagrams.

**DALL-E-Enhanced Approach:** Students generated visuals of normal operations and deviation scenarios for each HAZOP node, creating a visual HAZOP that showed the consequences of different process deviations.

**Comparative Analysis Assignment:** > For your assigned distillation process: > > 1. Complete the standard HAZOP worksheet using the template provided > 2. For each identified deviation with serious consequences, use DALL-E to create a visual representation showing: > - The normal operation condition > - The deviation scenario with visible consequences > - The safety systems that would mitigate the hazard > > 3. Evaluate which approach (traditional HAZOP or visual HAZOP): > - Better identifies potential hazards > - More effectively communicates risk to operators > - Would be more useful in safety training > - Has limitations in technical accuracy > > 4. Recommend a best-practice approach that combines traditional and visual elements

## Assessment and Evaluation

### New Assessment Approaches

1. **Visual Hazard Identification Quizzes:**
	* AI-generated scenarios with multiple hazards to identify
	* Students mark and explain each identified hazard
	* Technical accuracy evaluations of visual safety elements
	* Comparison with traditional text-based hazard identification
2. **Prompt Engineering Quality Assessment:**
	* Evaluation of students’ ability to create technically accurate prompts
	* Documentation of refinement process
	* Critical analysis of generated imagery
	* Technical accuracy verification strategies
3. **Visual Safety Communication Portfolio:**
	* Collection of student-created safety visualizations
	* Reflection on effectiveness for different audiences
	* Connection to process safety management principles
	* Evaluation of technical communication abilities

### Evaluation Framework for AI-Generated Technical Content

Dr. P developed a specific rubric for evaluating the quality of AI-generated chemical engineering imagery:

1. **Equipment Accuracy:** Correct representation of process equipment features
2. **Process Fidelity:** Accurate depiction of chemical processes and flows
3. **Safety System Representation:** Correct safety elements shown
4. **Scale and Proportion:** Realistic size relationships between components
5. **Environmental Context:** Appropriate industrial setting and conditions
6. **Human Factors:** Realistic operator interactions and PPE
7. **Technical Limitations:** Awareness of inaccuracies and their implications

## Potential Outcomes and Considerations

### Expected Benefits

* Enhanced ability to visualize complex hazard scenarios
* Improved engagement with technical safety content
* Better understanding of spatial relationships in process equipment
* Improved ability to identify potential hazards from visual cues
* More effective communication of safety concepts
* Development of visual literacy for technical contexts
* Bridging of knowledge gap for students without plant experience

### Potential Challenges

* Technical inaccuracies in AI-generated imagery requiring verification
* Time investment needed to develop effective prompts
* Risk of reinforcing misconceptions through visuals if not properly vetted
* Need for consistent verification of technical accuracy
* Balancing visualization benefits with traditional analytical methods
* Risk of student over-reliance on visual vs. analytical approaches

## Faculty Implementation Considerations

### Key Implementation Strategies

1. **Progressive skill development** in both safety analysis and prompt engineering
2. **Comparative approaches** showing traditional and visual methods together
3. **Integration with existing frameworks** like HAZOP and LOPA
4. **Critical evaluation emphasis** preventing over-reliance on AI visuals
5. **Scenario-based learning** enhanced through visual progression

### Important Considerations

1. **Technical accuracy verification** must be explicitly taught and emphasized
2. **Domain-specific prompt libraries** save significant time and improve consistency
3. **Visual literacy** is a distinct skill requiring dedicated development
4. **Balance of visual and analytical approaches** prevents over-reliance on either
5. **Misconceptions can be reinforced** if visuals aren’t critically evaluated

### Future Refinement Directions

If implementing such an approach, consider: 1. Developing a comprehensive chemical engineering prompt library 2. Creating a technical accuracy checklist specific to different process equipment 3. Implementing structured comparison between AI visuals and real plant images 4. Adding more quantitative analysis to complement visual hazard identification 5. Developing advanced prompt engineering training for technical accuracy

## Resources Developed

1. **Chemical Engineering Prompt Library:** Equipment and process-specific prompts
2. **Technical Accuracy Checklist:** Verification guide for different equipment types
3. **Visual HAZOP Template:** Framework integrating visuals with traditional HAZOP
4. **Safety Visualization Rubric:** Assessment criteria for visual safety communication
5. **Chemical Process Imagery Database:** Categorized collection of verified visuals

## Implementation Advice

### For Faculty Considering Similar Integration:

1. **Start with comparative approaches** that combine traditional and visual methods
2. **Emphasize technical verification** from the beginning
3. **Build a discipline-specific prompt library** progressively
4. **Integrate with existing frameworks** familiar to students
5. **Teach prompt engineering** as a distinct technical communication skill

### Technical Considerations:

1. **DALL-E currently struggles with:** Internal equipment details, proper scale relationships, some technical accuracy
2. **Strengths include:** Environmental context, general arrangement, hazard visualization, engagement factor
3. **Always verify generated imagery** against technical references
4. **Iterative prompting** is essential for technical accuracy
5. **Documentation of limitations** should be explicitly included in student work

*This case study was developed as part of the “Strategies for Integrating Generative AI in Engineering Education” workshop materials in collaboration with Claude-3.7 Sonnet.*