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ONCE UPON A TIME IN THE CASTLE OF ENGINEERING EDUCATION: THE MAGIC OF STORYTELLING FOR NEURODIVERSE STUDENTS (PRACTICE)

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ABSTRACT

Neurodivergent engineering students face unique barriers in learning environments. To increase accessibility, reducing cognitive load is essential for people with learning and

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intellectual disabilities. Storytelling is a unique approach for addressing this issue as it provides structure, encourages reflection, and engages multiple sensory experiences that can enhance students' interest in learning. Especially in engineering courses where multiple abstract and difficult concepts are involved, storytelling holds the potential to engage students while facilitating knowledge transfer and application. This concept paper reviews and summarizes literature to highlight the benefits of utilizing storytelling as a pedagogical tool for neurodivergent students in engineering education. Further, it discusses subject-specific context where storytelling can be applied to improve the overall learning experience of engineering students overall, and why they may benefit neurodivergent students specifically.

1 INTRODUCTION

Preparing technically competent engineers for industry requires the internalization of technical knowledge and the development of strong visualization and critical thinking skills. Engineering education often involves abstract and challenging concepts that necessitate unique pedagogical approaches beyond traditional lecturing styles. Such pedagogical approaches, however, may not include methods that adequately accommodate the diverse learning needs of neurodivergent students.

Neurodivergent students are those classified as having neurological differences such as attention deficit hyperactive disorder (ADHD), autism spectrum disorder (ASD), and a variety of learning disabilities. Studies indicate that neurodivergent students pursuing university education, including engineering degrees, represent a small percentage of the total student population. Though retention and graduation rates of neurodivergent students compared to their neurotypical peers remains largely unknown, research also suggests that neurodivergent students generally graduate at lower rates (Chrysochoou et al. 2022). One possible reason for neurodivergent students' struggles in engineering are challenges in executive function related to working memory. Working memory is the executive function responsible for processing, storing, and recalling information and concepts (Smith et al. 2016). To promote inclusivity and improve the retention of neurodivergent students, it is critical to employ creative pedagogies that address diverse learning profiles, including those that may contend with working memory challenges.

The Universal Design for Instruction (UDI) framework is one proposed framework to address such needs by modifying instructional practices to be inclusive of all students. It aims to reduce the barriers posed by learning environments using nine principles (McGuire et al. 2003). We propose that storytelling, as a form of instructional scaffolding, can be an effective way to provide simple and intuitive instruction as presented by the UDI framework while allowing space to meet several more principles of the framework.

This concept paper proposes the use of storytelling in engineering education to support inclusive learning environments through informational scaffolding. Specifically, this paper explores the literature to investigate current applications of storytelling in higher education settings and its potential benefits for neurodivergent students specifically through the reduction of cognitive load and the principles provided by the UDI framework. Furthermore, practical suggestions will be provided for incorporating storytelling into engineering classrooms.

2 BACKGROUND

2.1 The Universal Design for Instruction

The UDI framework aims to implement principles of universal design into various aspects of instruction, such as the layout of physical spaces, curriculum design, and pedagogical practices, among other aspects. There are nine principles within this framework that guide its implementation. According to McGuire et al. (2003) those principles are:

- **Equitable use:** Designing instruction that accommodates and promotes access to people with varying abilities
- **Flexibility in use:** Instruction including a variety of methods that caters to a wide range of individuals' abilities
- **Simple and intuitive:** Designing instruction without the assumption of students' backgrounds, skillset or concentration level by simplifying concepts
- **Perceptible information:** Designing instruction in a way that is accessible regardless of the students' sensory abilities
- **Tolerance for error:** Instruction considers varying rates of processing information and levels of student background in prerequisite skills
- **Low physical effort:** Designing instruction in a way that maximizes attention and minimizes unnecessary physical effort
- **Size and space for approach and use:** Designing instruction in a way that considers appropriate size and space for use regardless of the student's body size, posture, mobility, and communication needs
- **A community of learners:** Designing learning environments that promotes student to student interaction and faculty-student communication
- **Instructional climate:** Designing instruction in a way that is welcoming, inclusive, and promotes high expectations from all students

2.2 Challenges Faced by Neurodivergent Students in Education

Neurodivergent students often face difficulties rapidly processing information compared to their neurotypical peers (Smith et al. 2016). This is primarily due to challenges in working memory, which is responsible for conscious cognitive processing. When working memory is overwhelmed it can lead to cognitive overload (Dahlstrom-Hakki and Wallace 2022). In neurodivergent individuals, they may have limitations in working memory capacity that make them more susceptible to cognitive overload. As a result, instructional modifications aimed at reducing cognitive load are beneficial for neurodivergent students.

Several techniques can be applied through various instructional methods to alleviate the demand on working memory including simple language during instructional activities, leveraging prior knowledge, incorporating informational scaffolding, and providing ample opportunities for review to decrease cognitive load at any single point in time (Smith et al. 2016).

3 STORY-TELLING

Storytelling is a universal mode of information transfer deeply ingrained in humans and can take various forms. It has been shown to enhance comprehension of concepts and mastery of skills through connecting components. Landrum et al. (2019) highlights the multiple ways in which storytelling may be beneficial in an educational setting. These include creating interest, providing a structure for remembering course material, sharing information in a familiar and accessible form, and establishing a more personal student-teacher connection. Its application has been observed in engineering courses (Ball et al. 2015), other STEM subjects (Anastasiadis et al. 2018), and at different educational levels.

In engineering education, storytelling has been used to strengthen analytical skills and highlight the relationship between multiple components in complex problem solving. Ball and colleagues (2015) compared the learning outcomes of youth apprentices who investigated a sustainability problem through digital storytelling and hands-on exploration. The findings indicated that the storytelling group achieved equal learning outcomes to the control group while demonstrating an increased understanding of the interconnectedness of various components of the sustainability problem. This suggests that storytelling can help establish a connection between concepts.

In another study, Anastasiadis and colleagues (2018) explored a collaborative approach to storytelling in secondary schools using a digital platform called STORIES. The collaborative nature of this method not only improved students' understanding of the subject matter, but also enhanced their cooperative problem-solving skills. This finding is particularly valuable in STEM disciplines that require frequent collaboration. This study emphasizes the uses of storytelling as a collaborative and student-driven method of instruction.

Digital storytelling has also been used in undergraduate geography courses to promote deep learning, which involves the holistic integration of different facts. In a study conducted by Ryan and Aasetre (2021), students used digital story maps to enhance their understanding of geographical principles. The sequential structure of the stories facilitated a better grasp on concepts with temporal dimensions, such as the gentrification of an area. Students' reflections revealed a more concrete understanding of theoretical concepts as they applied them to real-life scenarios through the emotional impact of the stories.

These examples demonstrate the effectiveness of storytelling as an alternative or supplementary instructional approach, offering benefits beyond traditional methods of instruction for all students. As mentioned previously, for neurodivergent students specifically, the increased interconnectedness, real-life foundation, and guidance in cooperative problem-solving skills can help overcome challenges of executive functions.

3.1 How Storytelling Conforms with the Principles of the UDI Framework

Storytelling aligns with the principles of UDI, as evidenced by its diverse implementations and adaptability to different educational contexts. Whether stories are created by instructors or students, their application has been observed in geography courses, engineering apprenticeships, and secondary school science curricula. This flexibility, along with other notable features, enables storytelling to align with UDI principles. The alignment is specifically illustrated for the following six out of nine principles of UDI:

- **Flexibility in use:** Storytelling accommodates the needs of diverse learners by offering multiple methods of implementation. Instructor-generated stories have been explored (Landrum et al. 2019), while student-generated stories have been demonstrated on an individual or group level (Ball et al 2015, Anastasiadis et al. 2018, Ryan and Aasetre 2021). Such varied approaches highlight the potential for adaptable use in instructional settings.
- **Simple and intuitive:** Storytelling is a universal and familiar way of presenting information (Landrum et al. 2019, Bolkan 2021). The structure of stories enables students from different backgrounds and skill sets to comprehend the subject matter in an intuitive manner (Bolkan 2021).
- **Perceptible information:** Storytelling is delivered in various formats to cater to students' sensory abilities. For instance, the use of audio narration in digital story maps caters to both visual and auditory learners (Ryan and Aasetre 2021), showcasing the integration of different media in the storytelling experience.
- **Tolerance for error:** Storytelling can be adapted to account for varying rates of information processing and students' background knowledge. The content and

length of a story can be adjusted to accommodate students with different backgrounds of skills and knowledge.

- **Low physical effort:** Engaging in storytelling requires minimal physical effort for students, particularly when the story is generated by the instructor.
- **A community of learners:** Storytelling fosters collaboration when student teams work together to create stories, as observed in the study on the impact of the STORIES platform on collaboration skills (Anastasiadis et al. 2018). Furthermore, it facilitates interactions between faculty and students when they collaborate to generate story content for instructional purposes.

In summary, storytelling aligns with the principles of UDI by providing flexible approaches, simplicity, accessibility, adaptability, low physical effort, and opportunities for collaboration within the learning community. Its versatile nature allows for inclusive and effective instructional experiences for neurodivergent students and learners in general.

3.2 How Storytelling Provides Structure and Reduces Cognitive Load

Current research suggests that information conveyed through stories is often more easily understood since it is presented in a way that reflects how human brains naturally organize information – in a sequential structure (Landrum et al. 2019). This structure reduces the cognitive load of the listener allowing for easier comprehension of the information being conveyed (Bolkan 2021). Researchers argue that there may be neurophysiological reasons for which storytelling facilitates the learning process due to the involvement of characters in stories. These characters activate the listener's mirror neuron system, which allows them to simulate the experiences and emotions of the characters. As a result, the information becomes more engaging and memory retention is enhanced, facilitating the transfer of knowledge to new contexts (Landrum et al. 2019). Additionally, by using vivid and relatable examples, stories can connect and concretize abstract concepts that otherwise may be difficult to grasp (Anastasiadis et al. 2018, Ball et al. 2015, Ryan and Aasetre 2021). Bolkan (2021) notes that this is particularly beneficial for students who may struggle with more abstract or technical concepts, as stories can group these concepts in real-life context.

4 EXAMPLES OF STORYTELLING

The literature has shown two ways in which storytelling may be an effective instructional method for addressing the learning challenges faced by neurodivergent students in engineering. First, storytelling provides simple and intuitive instruction that naturally connects complex concepts and may be beneficial for many neurotypes, consistent with principles of the UDI framework. Second, storytelling reduces cognitive load by delivering information in a structured manner grounded in real-world contexts.

For instance, real-life scenarios can be effectively illustrated by using virtual experiments to study how a truss bridge deflects under different loading conditions. By applying narrative techniques to these virtual experiments, students are provided with context, promoting critical thinking and reflection based on their observations. This cause-and-effect relationship portrayed in the virtual experiment provides structures for students to understand the interconnectedness of concepts.

This could be taken one step further in augmented reality experiences. Augmented reality experiences can take the form of a storytelling journey, enabling students to explore and discover the progression of internal stresses in a loaded beam. This immersive approach could help students to develop an intuitive understanding of statistics and mechanics of material principles while processing information in a logical order.

Another example could be in the context of digital prototyping. Senior design projects provide a significant platform to showcase the evolution of a design from the initial stage to the final product. By employing computer-aided design (CAD) software in a land development project, students can iteratively design and explore various landscaping options for a given region. Incorporating a storytelling framework allows students to gain a comprehensive understanding of the roles of civil engineers, the design process involving permits, and the involvement of different stakeholders.

A final example could be a simulation-based scenario. In this scenario, a student could be asked to take on the role of a structural engineer for the seismic design of a building. This simulation would guide the student through the design and decision-making process to mitigate seismic hazards. Through the narrative style approach, students develop motivation and a sense of purpose by witnessing the practical implications of their decisions. Additionally, this provides students with a structure that they could replicate later in their professional engineering experiences.

5 IMPLICATIONS FOR ENGINEERING EDUCATION AND NEURODIVERGENT STUDENTS

Though these examples can be beneficial for all students, for neurodivergent students the additional structure of narrative techniques would be particularly helpful in organizing the necessary information and possibly help with later recall without causing cognitive overload. Using context heavy problems, while important for a richer understanding of engineering problems and later recall, can increase the cognitive load of neurodivergent students (Dahlstrom-Hakki and Wallace 2022). Providing the scaffolded structure of a story, and playing into a form of learning ingrained in the human psyche to form connection, may provide neurodivergent students with an avenue to navigate complex, context heavy problems with high cognitive demands.

While storytelling has been applied in diverse ways, there are still unexplored avenues in the research literature. As we have shown, storytelling can be a critical technique in the pedagogical arsenal of engineering education, creating relatable, reality-grounded scenarios that aid students in developing a deeper, more complex understanding of engineering topics. In the move towards diversifying engineering, engineering pedagogy must adapt to including diverse learning needs. We propose that the inclusion of storytelling in engineering education pedagogy will be beneficial to not only improving understanding of complex topics in engineering classrooms, but by increasing accessibility of these topics for neurodivergent students. By including pedagogical techniques that are accessible for neurodivergent students, we help students of many different backgrounds and needs.

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