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Generative Learning in Two Community-Based Experiential Undergraduate Courses

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This research to practice paper analyzes the innovative teaching elements of two community-based experiential undergraduate courses. Experiential learning on its own shifts a class from a more traditional format to "an approach that is semi-structured and requires students to cooperate and learn from one another through direct experiences tied to real world problems" [1, p. 4]. When engaging with the community through experiential learning, additional perspectives are integrated into learning with the intent that all parties will benefit. This can be achieved through multiple course designs, two of which are the focus of this article. Instructors, by necessity, must adopt a more facilitative and guiding role in their classroom. As a course format, experiential learning is not new, particularly in engineering design courses. However, the pedagogical practices within experiential learning are constantly changing as informed by evolving evidence from research-based strategies. One such practice has provided promising evidence of deeper learning in recent decades: generative processing [2], [3]. By embedding these effective pedagogical principles within experiential learning, innovative teaching practices emerge. To illustrate this point, we present our research from two undergraduate experiential courses, one engineering design course and one science leadership and outreach course, at a southwestern university. This comparison provides a broader view of the application of innovative pedagogy across multiple contexts.

Generative Processing

Generative processing presents a constructivist perspective of active learning through building new knowledge structures and making meaningful inferences based on new information [4], [5]. In the context of an undergraduate course, students receive new ideas from the instructor in the form of lecture, media, or experiences, then must transform it into usable knowledge by connecting to existing schema [2]. Mayer [6] breaks down the process into three cognitive steps: selecting, organizing, and integrating new information. The learner selects relevant information, organizes it through internal connections in working memory, and builds external connections in long-term memory to be able to use the information.

Strategies to Promote Generative Processing

Fiorella and Mayer [2], [3] identify eight strategies to promote generative processing. We summarize these briefly below.

Summarizing requires the learner to concisely state the main points of a lecture, reading passage, discussion, or another source of information. Studies employing summarizing have found this strategy can improve reading comprehension and metacognition to assess the level of understanding.

Mapping refers to creating a visual representation of organized, linked ideas (e.g., concept map, graphic organizer) from a lesson or learning materials. Learners convert the written text to spatial arrangements by identifying key concepts within the information. Pre-training may be necessary in order for learners to understand contextual usage of various forms of mapping styles.

Drawing refers to the learner creating an image by hand or electronically from the learned information. Evidence is promising that this strategy benefits learners from primary through post-secondary levels. Learners need structured information on elements of the drawing as well as reduced emphasis on the mastery of technical drawing.

Imagining pertains to the creation of mental images of information provided to the learner. Imagining, while similar to drawing, removes the pressure on learners to produce technically-skilled drawings; however, studies indicate that a high level of prior knowledge is necessary in order for the learner to effectively use imagining as a generative process.

Self-Testing involves the learner developing and answering questions about the material. Studies on self-testing suggest that this strategy can promote long-term retention when used repeatedly and in high frequency. Learners also need to be provided with formative.

Self-explaining is characterized as the learner providing oneself with an oral or written explanation of the material being learned. By extracting the pertinent information form the learning and restating it, this method can assist learners in the understanding of material requiring complex cognitive processing.

Teaching pertains to peer tutoring, group learning, small group activities, or any other activity with the objective of assisting others in the learning process. Teaching involves three phases, the preparation for teaching and the act of teaching, and the interaction with others. Research indicates that the preparation for teaching combined with the act of teaching promote the most long-term storage of information.

Enacting refers to physical movement during the act of learning, including gesturing and dexterous manipulation of objects. This strategy relies on the interdependence of behavior and cognition to enhance generative processing in learners.

Experiential and Community-Based Learning in Higher Education

Experiential learning, most simply defined as learning by doing, can occur in multiple contexts at the university level. For example, many undergraduates have opportunities for hands-on laboratory time, internships, and service-learning programs. Through these experiences, ideally four stages should occur: participating in the experience, reflecting about the experience, conceptualizing (understanding) what they experienced, and applying what they learned in a similar setting [6]. When bringing experiential learning into the classroom, particularly within a course focused on engineering design, it can integrate authentic learning experiences into students' plan of study and daily lives [1].

A recent systematic review [7] conceptualized experiential learning in engineering education as self-school-community. It draws connections between students' lives and needs (self), how they experience engineering curriculum and instruction (school), and the impacts of general well-being and contextual environmental factors (e.g., community) [7]. This interdependence between engineers, knowledge, and the community creates an opportunity for a variety of approaches to produce successful outcomes. Higher education institutions and faculty can tailor experiential, community-based learning practices to their specific contexts. For instance, these concepts could comprise one unit of study, one course, or even an overall theme within a program.

Faculty instructors innovate through combining curriculum and instructional methods in novel ways. For example, students may be practicing CAD or drafting skills, but the instructor takes them to a children's museum and assigns a redesign of exhibits for increased accessibility or the curriculum may analyze civil engineering case studies leading up to the Olympic Games. Instructors have also combined disciplines in novel ways. An engineering course may integrate a writing unit to support first-year engineering students or simulate real-world contexts with corresponding tools and materials. Tembrevilla and colleagues [7] further suggest that students may benefit from a variety of experiential assessment strategies at multiple timeframes. Innovations in assessments include students creating "The Elevator Pitch" in order to develop communication skills [8].

Research Into Practice

This article aims to bridge the gap between theory and practice through applying the conceptual framework of generative processing and experiential learning instructional practices to community-based STEM courses. Evidence of effective learning outcomes has been presented for each practice alone, however there are few contexts where they are combined. It was this unique lens for innovative instruction that inspired the question: How do instructors implement generative processing concepts through experiential learning in community-based courses?

Methods

The practical context for this analysis stems from a southwestern private university within two upper-level, community-based undergraduate STEM courses. All artifacts considered in this research are existing components of the courses with the researchers as outside observers.

Participating Courses

Engineering Design II (EDII) forms mixed-major groups of engineering undergraduates to design solutions for a variety of local businesses, organizations, and schools. Upon partnering groups with their clients, EDII students lead meetings throughout the semester from the initial briefing to design reviews, culminating in a prototyped solution for the client. Successful outcomes for this course include teamwork dimensions focused on knowledge, skills, and abilities (KSAs) [9].

Science Leadership (SL) partners groups of science-majoring undergraduate students with K-12 public school classrooms to collaboratively complete inquiry-based research, culminating in an on-campus presentation. Successful outcomes of this course are based on the

NGSS Science and Engineering Practices for the K-12 students (SEPs) [10], and knowledge, skills (e.g., contextual 21st century skills) [11], and abilities for the undergraduates.

Data Collection and Analysis

Through the lens of innovative teaching practices, syllabi and course assignments were examined as student-facing course components. Framework analysis [12] was applied using generative processing strategies [3] to assess the prevalence and context of each as a teaching practice.

Concurrent analysis was undertaken via observations by the researchers. Essential experiential elements of each course were observed, with the researchers observing small groups of students in the context of their projects (e.g., capstone for EDII, school outreach for SL). These observations triangulate the analysis of innovative teaching practices through student learning outcomes.

Findings

Six generative processing strategies were present in the experiential learning courses (see Table 1) particularly through the course design in both EDII and SL. Both courses were found to be rooted in contextual generative learning, particularly learning by teaching and enacting, considered the most high-leverage generative processes [3]. To further examine the context in which these strategies were present, we detail each further below:

Summarizing [2], [3] was integrated into the EDII course materials, and embedded in SL. In EDII, students summarized and shared the minutes from client (community member) meetings with their design groups and faculty mentors. They also summarized their takeaways from group interactions such as conversations about their design and roles to turn into faculty. This generative strategy was revisited multiple times in the course and was used by instructors to facilitate learning and communication within the context of design teams. In SL, students summarized the processes and terminology relevant to the research process to K-12 students. Additionally, they summarized research findings of K-12 students during the collaborative development of the research poster. Students also summarized the outcomes of meetings with K-12 students at weekly increments during class discussion and in course assignments. Summarizing was used throughout the course in multiple ways as a means of effective communication to K-12 students and reflection during the course. In SL, students summarized in weekly individual video reflection assignments and in while class discussions highlighting observations, successes, and improvement areas for the following meeting.

Mapping was emerging in EDII lessons and emerging in SL. In EDII, students created flowcharts to connect the objectives and functions of components in the design. There were other moments in the course where students may have chosen to engage in mapping, but in general the complexity of the material required larger tables and spreadsheets. In SL, students had the option of using seating charts to learn the names of K-12 students. Additionally, some students chose to integrate graphic organizers and charts into presentations to assist in explaining the data collection process to K-12 students. The course, however, did not explicitly require the use of mapping at any particular stage.

Drawing was embedded in EDII and was essential to the capstone project in both the design and prototyping stages. Design teams sketched their ideas initially to increase innovative thinking, then one or more members continued conceptualizing the team's prototype through drawing/design programs (e.g., CAD). In particular, the application of drawing and design was emphasized in this course because instructors knew that students had background in this area. Though embedding CAD in this type of capstone course may not be a new idea, bringing sketches and designs into conversations with clients who may not have much of an engineering background created a different learning environment than students had experienced previously.

Self-explaining was integrated into EDII through a variety of course assignments that led students to create charts and organized tables to aid in understanding and presenting the more challenging aspects of their design. For example, students created a color-coded feasibility chart to aid in the explanation of more complex decision-making processes. Teams' notes, drawings, maps, and schematics were integrated into course materials and made appearances in their slides for client briefings.

Teaching was embedded into the EDII course and embedded in SL. In EDII, teaching peers and clients was essential to the capstone project. Through establishing group roles, each team member was responsible for one or more aspects of the project, detailed in the course materials. They explained, asked, and answered questions from peers and clients in order to fully understand their component of the project. The inclusion of the group roles' responsibility to the whole and how they interact to create a design sets the students up to learn by teaching peers from the very beginning of the course. Teaching K-12 students was the driving generative process in SL. The course objective was to facilitate K-12 students in the process of inquiry-based learning. Over a period of 15 weeks, students prepared for teaching, taught the material, and interacted with K-12 students. They taught K-12 students how to design an experiment, how to collect data, how to analyze data, and how to communicate results of the experiment.

Enacting was embedded into the EDII capstone and integrated in SL. In EDII, instructors set up a structure for verification procedures for student groups' final designs. This is a direct application of learning by enacting - testing the prototype for its intended use by simulating the use case. Through requiring that the design be verified, instructors are ensuring that students take the client perspective and use a high level of generative processing to determine if the design passes or fails each criterion. In SL, students are required to arrange virtual meetings with the K-12 teacher and students. During this time, students develop 21st century skills through the process of enacting as they physically manipulate camera and audio equipment, computers, and videoconferencing platforms. As they handle the equipment and applications, students learn to host and conduct virtual meetings, record sessions, screen share, and troubleshoot technical issues.

The effects of these innovative teaching and course design practices were observed in each course's community-based components. In the EDII course, the client briefings were a focus as one design team worked with an instructor to follow and present their design process. Students began by explaining their own roles in the project, noting that they were each responsible for a different component as well as the whole. This highlighted the learning by teaching aspect of a design team, which was structured by roles in this course. Throughout the course, team members would speak about their tasks as part of the whole, often contextualizing their decisions in the other simultaneous decisions being made by the team. In the early briefings, it became apparent that students were using strategies for self-explaining. Students often had notes in front of them, as well as their slides, as they explained more technical concepts they had learned in class and applied to the capstone project. Self-explaining was built into a few course materials but became a more focused behavior they employed as a support through the team nature of the client briefings. Drawing and enacting were two generative processing techniques that students iterated through toward the end of the project, as they designed and fabricated components, tested them, and then redesigned as needed. The team also used their budget to purchase multiple versions of specific prototype components so they could enact several versions and apply verification procedures to determine the best option.

Overall, the community- and project-based nature of the EDII course produced drawing, teaching, and enacting as generative processing strategies. Learning by teaching was observed through design teams' collaborative presentations where each member explained their components in context of the whole project. Drawing was highlighted as a visualization strategy for the eventual prototype, and enacting was perhaps the most crucial as the team connected their ideas into the final design solution.

SL students engaged in summarizing through communication with teachers in preparation for weekly meetings. Students would send information summarizing lesson topics, request information and follow up with previous lessons in a brief explanatory email. SL students served as primary teacher or facilitator or the lessons. They demonstrated their preparation for the teaching with the development of prepared slides presentations. These slides were to anchor the teaching and served as a guide for K-12 students through the learning process. Interaction was evident in the questions SL students asked of K-12 students, both content-based and relationship-development-based. SL students requested seating charts from teachers to assist in learning the names of K-12 students. This mapping strategy resulted in the use of K-12 students names during the lessons and in-person. Furthermore, concept maps and graphic organizers were occasionally used in slides to explain information to students in the data collection stage of the experiment.

The SL course is designed around learning by teaching for the primary process for generative learning. Summarizing was integrated throughout the course, but not to the depth as teaching. Furthermore, while mapping was integrated and enacting was emerging, they were dependent upon student choice, not required course components.

In summary, EDII and SL implement generative learning processes to enhance the experiential learning for students. Both courses implement high-leverage processes, including teaching and enacting, in different contexts. Due to the product design component of EDII, the course contextualized more generative learning processes such as drawing and enacting. The student-as-teacher component of SL lends to teaching as the primary generative learning process. This shows that generative processing can be successfully implemented through a large variety of strategies or a focused path toward one with the best fit for the context.

Future Directions

These results suggest that EDII and SL do provide examples supporting current research on generative processing. Examining the community-based course designs and instructional materials given to students, along with observing students' learning as it occurs, allows us to unravel part of the thread from teaching to learning. However, this research to practice paper has only examined observable evidence that generative processing occurred. To dig into the intent of the instructors and the perceived experiences of the students, additional research questions must be asked and methods employed. Next steps for this research may include focus groups among faculty, students, and design/mentoring teams.

Learning by teaching and enacting are two of the more cognitively demanding generative processing strategies, and both were salient in these courses. The experiential community-based nature may have contributed in some way, but further exploration is needed. For example, if the effort to select, organize, and integrate new information changes as a result of involving other non-peers [13], then this could have implications for instruction. To turn in this research direction, a course with similar content but without community involvement could be included to further inspect generative processing in both contexts.

For practical purposes, by comparing engineering courses to other STEM courses such as SL, more innovative teaching practices can be implemented. For instance, if an engineering professor wanted her students to better communicate engineering concepts to non-engineers, arranging for interactions with middle school students is something that has worked successfully in SL (learning by teaching). On the other hand, SL could implement more varied strategies. For instance, mapping could be incorporated in lesson development as undergraduates could create a graphic organizer to structure their weekly lesson plan. By mapping out the weekly lesson goal and activities, they would be more intentional about selecting and organizing the most relevant science concepts to integrate in an engaging way. Applying the lens of generative processing to unique contexts such as experiential courses can continually improve students' learning.

Future research would benefit from combining research-based learning strategies such as generative processing to unique courses like those in this study. Further, the implications for instruction may be highly contextual, but they are essential for course design and ultimately, students' learning. High-leverage teaching strategies such as generative processing provide a strong foundation for building experiential or any other courses, but as with any innovative practice, necessitate further research on learning outcomes.

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Table 1

Evidence of Generative Learning Strategies in EDII and SL

GP Strategy	Definition (Fiorella & Mayer, 2016)	EDII	SL
Summarizing	Concisely state the main points of learned information	Integrated	Embedded
Mapping	Create a visual representation of organized, linked ideas	Emerging	Integrated
Drawing	Create an original image to represent an idea	Embedded	N/A
Self-Explaining	Provide a verbal or written description to aid in understanding complex material	Integrated	N/A
Teaching	Assist others in the learning process by preparing, teaching, and interacting	Embedded	Embedded
Enacting	Physically moving or manipulating objects to enhance learning	Embedded	Integrated

Note. GP = Generative processing. Emerging = present in the course at one or a few discrete time points, Integrated = incorporated into larger course units, Embedded = essential to accomplishing course tasks and goals.