IUSE: Knowledge mobilization practices employed by mechanical engineering students to solve design problems

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Introduction & Background: Employers commonly cite that engineering graduates struggle to apply classroom knowledge to real-world applications [1],[2]. In consideration of such observations, this NSF project seeks to investigate the knowledge mobilization processes of mechanical engineering students in professional contexts for the purpose of strengthening real-world problem-solving abilities. The project, as a whole, is composed of three specific research aims: (Aim I) identifying effective ways to match the structure of student knowledge with the structure of the engineering problem, (Aim II) identifying how environmental factors affect knowledge mobilization processes, and (Aim III) utilizing findings from Aims I & II to design an intervention geared towards optimizing student knowledge mobilization processes.

In their entirety, Aims I & II consist of three student experiences: a junior design course, an internship, and a capstone course. The efforts outlined in this work draw primarily from the junior design course phase of the project, and the organizing principles students employ when applying abstract Course Learning Outcomes (CLOs) to real-world applications. This topic is addressed in [3] using the Semantic Gravity dimension of Legitimation Code Theory (LCT) [4]. Specifically, [3] explores how instructors assist students in integrating knowledge over a range of STEM topics. On the other hand, Pott & Wolff [5] have applied the Specialization dimension of LCT to a university-level fluid mechanics course to measure knowledge retention in students. In consideration of formulaic and real-world societal aspects inherent to contemporary engineering design problems, study [6] employs LCT Semantic Gravity and Semantic Density to analyze engineering lecture practices of teachers. In contrast to the existing literature, this study shifts its focus towards the problem-solving processes employed by mechanical engineering students and does so under the LCT Autonomy dimension outlined in [7]. This framework provides a way to answer questions about the disciplinary contents and purposes invoked by students in a design setting. By gaining insight into the student thought-process of design, engineering faculty can make more informed decisions around guiding their classroom through effective Autonomy pathways. In this paper, findings are presented specifically on the knowledge mobilization techniques of students for a black box model assignment from a junior design course.

Methodology: Subject recruitment commenced shortly after receiving exemption status from the Institutional Review Board (IRB). From fall of 2024 to the spring of 2025, a total of 392 mechanical engineering students, enrolled in a public R1 university-level junior design course in the Pacific Northwest, were emailed for recruitment purposes. In alignment with a maximum variance approach, a demographic survey was sent to recipients who expressed interest in the study. Upon review of the polling data (i.e., GPA, ethnicity, age, first-generation student, etc.), a total of 24 candidates were chosen to participate in the junior design phase of the project. A subset of this sample population also participated in the internship and capstone portions of the study. Across all three stages, a total of 149 hour-long semi-structured interviews [8], 68 audio recordings of presentations and meetings, as well as other student-produced artefacts (homework assignments, journals, CAD drawings, etc.) have been collected for triangulation purposes.

This work specifically focuses on the findings from the fall 2024 junior design course, in which students were provided an outdoor camping prompt for their project. The problem-solving processes employed by mechanical engineering students to complete a two-part homework assignment are examined. First, students are tasked with generating inputs and outputs (black box model) for their design and then, in the latter phase, determining the functional requirements for said inputs and outputs. The transcribed interviews are analyzed using the Autonomy dimension of the LCT framework guided by an Autonomy translational tool (Table 1). This device partitions knowledge contents used by students – Positional Autonomy (PA) codes – and purposes for applying this knowledge – Relational Autonomy (RA) codes – and places them into a hierarchy of insulated delicacies in which the (+) and (-) symbols represent how close or far the knowledge and purposes are from the core target, respectively. The translational tool was constructed from a combination of CLOs, listed in the junior design course syllabi, as well as common themes found in the RA and PA codes from the fall 2024 interviews. For inter-rater reliability a team of four researchers performed independent analyses. Findings were then presented in group discussions to compare prevalent themes. For anonymity purposes, participants have been provided with pseudonyms – Participant A, B, C, and D.

Table 1: LCT Autonomy Translational Device

PA/RA	1st Level	In this study:	2nd Level	In this study:
+	Target	Mechanical engineering knowledge for solving mechanical engineering problems	Core (++)	**C:** Course knowledge **P:** CLO mastery
			Ancillary (+)	**C:** STEM Knowledge **P:** Meeting CLO-related project milestones (functionality, inputs/outputs, customer needs, evaluation, etc.)
-	Non-target	Other contents / purposes	Associated (-)	**C:** Internship experience **P:** Group coordination / organization
			Unassociated (--)	**C:** Anything else **P:** Any other reason

Results: The problem-solving processes of four participants (A, B, C, and D) are presented and analyzed to reveal the knowledge constituents and practices employed by students in completing their black box model assignment. PA and RA codes are plotted in Figure 1. A proper interpretation of the diagrams requires the reader to start from position (1) and trace a path, along the direction of the arrow leading to the next consecutive integer. This process is repeated until reaching the final numerically labeled circle, representing the entirety of the student's problem-solving process.

Participant A begins their assignment by contemplating necessary resources such as, "…a stove…heating area…[and] some sort of water source…to fill [their] pot…to clean [their] dishes". In LCT terms, the subject accesses outside brainstorming knowledge (--) to satisfy ancillary (+) customer needs, labeled as point (1) on Figure 1a. They then use the assignment (++) to obtain "…heat and light…" as outputs (+), thus corresponding to point (2) on the diagram. In approaching the, "…funkier…human inputs…" category, the student acknowledges their confusion (--) and uses this unassociated content for the unassociated purpose (--) of finding "…some good examples…" the teacher has presented in class (3). Participant A then uses these lecture examples (++) for the core purpose (++) of learning about concept generation from an abstract point of view and considering inputs for a design they, "…probably never would have thought of". The pair of codes is annotated in Figure 1a as point (4). This CLO knowledge (++) is then applied to the completion of their black box model (+), taking inputs such as, "…the hand and foot…to pump water" (5). After developing the inputs, the subject draws ancillary knowledge (+) from an engineering, "…coding course…" to carefully, "…think about [their] steps…", and the order of their inputs (+) (6). In establishing these "lines" of connection from the input portion of the assignment (++), Participant A is able to determine the, "…heat and combustion…" mechanisms needed (+) for their outdoor kitchen table design, ending at point (7) on the diagram.

Participants B & C begin by using the assignment (++) to determine, "…what's going in and what's coming out…" (+) of the black box model. They then recognize their confusion (--) around the key terms, "…material…signal…[and] energy…", used in the assignment, leading them to seek a deeper understanding of CLO-related contents (++), such as design functionality, inputs, and outputs. These correspond to the points labeled as (1) and (2) on Figures 1b and 1c. After this point, their paths diverge, as described subsequently.

Participant B takes several steps involving team meetings outside of class (--) for the purposes of group coordination (-) and making progress on the assignment (+). They also recall a prior class submission (--) stating, "…when we submitted our design proposal, we were marked down…because we were too far ahead…" motivating them to be more cautious (--) and to ask, "…did we construct [the black box] in the right way?". To avoid future penalization (--) the group "…didn't wanna go too far in the black box…" assignment (--).

On the other hand, Participant C consults with a group member (--) to seek a clearer understanding of the energy input concepts (++), labeled point (2) on Figure 1c. Participant C's next steps consist of using knowledge content from prior courses. They consider physics principles, "…like energy…[from] electrical fundamentals…moving power…" and then use this to see "…the correlation with electrical…and human energy, it's still like you have handles…for humans to…move it". Essentially, they are using knowledge from prior STEM courses (+) for the purpose of understanding the concept (++) of human energy input. Participant C's problem-solving process, points (3) – (8), primarily belong to the 1st and 4th quadrant of the domain.

Participant D begins the assignment by meeting with their group and "…drawing things on a whiteboard", thus using unassociated constituents (--) for associated purposes (-), as indicated by point (1) on Figure 1d. Next, they transition to (2), by drawing out their "customer requirements" from the priorly completed HOQ assignment (++) to appropriately plan their design schedule, "…in time for [their] final presentation" (+). Participant D proceeds by using, "concepts of…mechanical energy…" (+) to organize inputs and outputs (+), as labeled by (3). Their following step (4) would be to consider a power source (--) such as, "a battery" for powering their design (+). After completing the assignment, Participant D reflects on the course organization, stating that the black box assignment, "…would be more helpful after our concept generation…because we…were kind of thinking of a design without actually having our concept generation homework". In other words, point (5) on Figure 1d corresponds to the student performing the unassociated (--) action of reflection to consider ways to organize assignments they believe would be more beneficial to the ancillary (+) task of project completion.

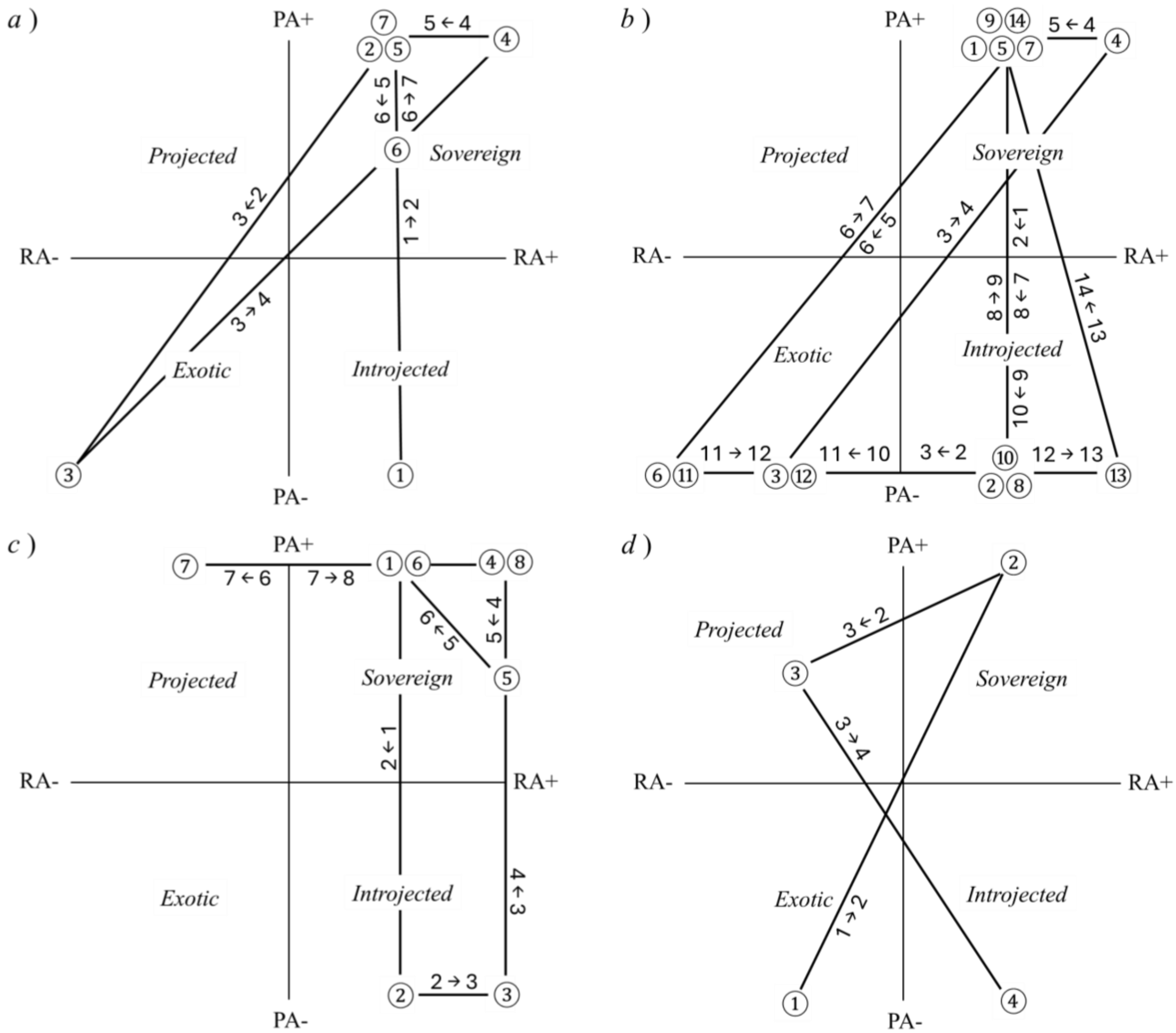

Figure 1: Autonomy pathways for participants: *a)* A, *b)* B, *c)* C, and *d)* D.

Discussion & Conclusion: The findings indicate that students take a diverse array of Autonomy pathways in their design problem-solving approach. Such variations may result from factors including, but not limited to, their elected design project, their applied knowledge constituents, grade concerns, and their perceived purpose of the assignment. The trajectories taken by students provide insights into how instructors may better guide students to take effective design strategies.

For example, when Participants A, B, and C encountered confusion or ambiguity around the assignment, subjects from this portion of the study took this as a signal to seek out junior design course knowledge for the purpose of understanding CLO content. This suggests that having readily available information for the students could streamline the efficiency of their problem-solving process. Applying this solution to Participant A, for instance, may have circumnavigated their need to access *Exotic* contents and purposes, eliminating step (3) from their process. Instructor planning and organization [9] is seemingly a key factor (i.e., placement of links in assignments, proactive scaffolding by allocating additional attention to challenging topics during lecture, etc.); thus, emphasizing the importance of being receptive to student feedback [10].

Participants B & C start from a common origin but end in quite different places. Their respective Autonomy tours illustrate some of the distinguishing factors in their trajectories. It is apparent from the analysis that Participants B & C encounter barriers around tacit definitions of technical terms. To circumnavigate these barriers, Participant B relies on knowledge widely insulated from the target content without ever quite returning to CLO mastery. Initial confusion around the material (--) appears to motivate Participant B to seek a conceptual understanding of the material (++). However, performance concerns (--) ultimately discourage further progress (--). On the other hand, Participant C stays primarily in the *Sovereign* and *Introjected* quadrants of the Autonomy plane, leading them to draw analogies and connections between prior classes and design-related CLOs. This suggests that additional instructional efforts, geared towards clear definitions and expectations [11] may be beneficial to student comprehension of material. Similarly, the existence of varying student knowledge-mobilization processes suggests that students may benefit from an optimal instructor-prescribed Autonomy pathway.

Participant D's final Autonomy position (5) is noteworthy because it reveals how they see the assignment targeted towards project completion, rather than CLO-mastery. In consideration of this, instructors may find it prudent to emphasize the relative importance of CLOs tied to a given assignment by including "Instruction" or "Purpose" statements in the assignment [12].

The findings from this smaller study uncover paths for effective problem-solving approaches in the context of real-world design applications and providing options for faculty to leverage these tools towards CLO mastery. Such takeaways fit under the broader scope of the project and contribute towards the fulfillment of Aim (I) and Aim (II) objectives.

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