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The Performing Engineer: Engineering Opportunities for Interdisciplinary Transfer

Ms. Lydia Wilkinson, University of Toronto

Lydia Wilkinson is a lecturer in the Engineering Communication Program at the University of Toronto, where she coordinates communication instruction in the Chemical Engineering department. Her research focuses on interdisciplinary skills transfer and investigates the mechanisms through which students apply their Humanities learning to their Engineering disciplines.

The Performing Engineer: Engineering Opportunities for Interdisciplinary Transfer

Representing Science on Stage, a theatre elective for engineers at the University of Toronto introduces students to theatre and performance by analyzing and performing selected plays about science. The intersection of engineer and performer has long been a part of the course experience and of particular interest to the course coordinators, who observe their students pulling from both these spheres as they develop new and innovative ways to tackle the challenge of theatrical development and performance. To engage this relationship more explicitly, the Performing Engineer assignment asks students to consider the ways that they are bringing together and transferring skills between these two disciplines. Student responses to this assignment identify a number of strategies from the course that improved their work in engineering courses and engineering design challenges. Interviews with a number of these participants highlight the value of adapting and applying skills in alternative settings to understand their value within an engineering context.

Arguments for a liberal education for engineers identify a number of positive outcomes stemming from required courses in the Humanities and Social Sciences: through immersion in the liberal arts students become more culturally aware, are capable of inter- and cross-disciplinary collaboration, have stronger communication skills, and are capable of learning outside of their discipline even after leaving the academic environment [1-9]. While these outcomes and their importance are widely articulated, there is less discussion about the mechanisms by which these benefits actually develop. In other words, because the positive outcomes of a liberal education are often observed and articulated in retrospect, the pedagogical constructs and cognitive models that scaffold these later behaviours are often unexplored. A more comprehensive understanding of how and why these skills develop can be gained by observing the student behaviours and instructional practices that govern some student experiences in the liberal arts.

Representing Science on Stage, a theatre elective for engineers at the University of Toronto provides one space in which these interactions can be observed. In this theatre course for engineers we introduce participants to theatre and performance as they analyze and perform selected plays about science. While the course is allocated as a Humanities and Social Sciences (HSS) credit, it is led by faculty from the Engineering Communication Program [ECP]. This service unit within the Faculty of Applied Science and Engineering [FASE] supports curriculum development and delivery in communication and design across all departments. As a result, alongside our work in this course we work with engineering colleagues in core technical courses and plan standalone communication courses, giving us insight into content and modes of instruction from the engineering discipline. With this background, we can challenge our students to engage with a liberal arts subject, while appealing to their technical expertise and knowledge from the broader engineering curriculum.

Over the course of the semester students in our course are tasked with developing an original scene, analyzing three theatrical texts, and performing an excerpt from one of these texts with a group of their peers. As we work through these activities we make use of our students' core scientific knowledge and interest to increase the relevance and accessibility of the new discipline, while also supporting their transition by providing a class environment that shares similarities with a typical engineering classroom. In addition to FASE faculty and students, the course takes place within a FASE building, and we frequently and explicitly refer to other FASE courses and events. While our students may be evolving as performers, they are doing so against the familiar backdrop of their engineering degree and identities. This intersection of engineer and performer has long been a part of the course experience and of particular interest to the course instructors, as we observe our students adapting techniques from both spheres as they develop new and innovative ways to tackle the challenges of theatrical development and performance.

Intrigued by these moments of disciplinary transfer, we created a course assignment, the Performing Engineer, to encourage our students to reflect upon the ways that they bring together and transfer skills between the engineering and theatre disciplines. The assignment directs students to "consider how [they] developed and applied approaches from both disciplines—theatre and engineering—to identify points of transfer between [their] studies as an engineer and [their] experience as a performer." Alongside a description of their process and the techniques that they applied within this process, students are also asked to consider the future implications of this type of transfer and in turn the future utility of the skills learnt and practiced within our classroom.

This paper reviews and discusses written responses to the Performing Engineer. It also makes use of previously scheduled interviews with five students in the class. These interviews were arranged as part of a larger qualitative study, *Engineering and Humanities Intersections*, which compares student experience across four liberal arts sites including our classroom; in conjunction with the assignment the interviews provided a unique opportunity to discuss issues raised in the written responses, and to give some students an opportunity to further reflect on their skills or knowledge transfer.

Skill transfer/knowledge transfer

Interdisciplinary skill transfer in engineering education is a developing field of study. Research into transfer within disciplinary domains reveals the importance of mastery as well as the role of metacognition in revealing opportunities for transfer [10, 11]. Some research into interdisciplinary epistemologies highlights the domain-specific nature of epistemological development [12]. While these two research fields discuss the cognitive underpinnings that support transfer, neither takes up the systems or mechanisms through which mastery of this knowledge is transferred and adapted between disciplines. Liyange et al look to research in business administration and organizational behaviour to develop a knowledge transfer model for the engineering context. While specifically interested in the methods that engineering firms may use to cultivate knowledge transfer between employees, their work provides a useful review of knowledge-transfer models in business [13]. They borrow from Aliva and Leidner to differentiate between different perspectives of knowledge, as a state of mind, object, process, condition of access to information or a capability [14]. In this framework knowledge transfer can take place around skills and capabilities as well as information. While transfer in the workplace is typically understood to occur between two individuals, when an expert shares their knowledge through various channels (training, mentorship, manuals) with a novice or learner, we might also see knowledge transfer occurring independently, as an individual transfers their expert disciplinary skills between different sites of learning or activities.

Models of knowledge transfer configure what is happening in these moments using one of two frames: knowledge transfer as communication, or knowledge transfer as translation. In their discussion on knowledge transfer as communication, Nonaka and Takeuchi conceive of knowledge transfer occurring through four different sites or types of learning[15], illustrated in the figure below.

From /To	**Tacit**	**Explicit**
Tacit	*Socialisation* Creates *sympathised* knowledge through the sharing of experiences, and the development of mental models and technical skills. Language unnecessary.	*Externalisation* Creates *conceptual* knowledge through knowledge articulation using language. Dialogue and collective reflection needed.
Explicit	*Internalisation* Creates *operational* knowledge through learning by doing. Explicit knowledge like manuals or verbal stories helpful.	*Combination* Creates systemic knowledge through the systemising of ideas. May involve many media, and can lead to new knowledge through adding, combining & categorising.

Figure 1. Nonaka and Takeuchi knowledge transfer model [16]

This model of knowledge transfer is of use in understanding the activities leading to transfer in the *Representing Science on Stage* classroom, as students participate in various activities that fall between and within each of these quadrants. Arguably, the act of reflecting upon and recording their experiences within the Performing Engineer requires that students concretize their knowledge through its externalization: as their tacit experience is documented and shared in the report. Knowledge transfer as translation uses translation as an analogy for the act of understanding or decoding unfamiliar language and concepts as knowledge is passed from expert to novice. This analogy is less useful within this context as students are transferring already familiar concepts between sites.

Liyange et al build on both theories to propose a procedural model for knowledge transfer. Their process involves four steps:

1. Knowledge awareness: identification of knowledge worth transferring;
2. Knowledge acquisition: acquiring this knowledge;
3. Knowledge transformation (which may involve translation): converting the knowledge to its new context;
4. Knowledge application: using this new knowledge. [13]

While students in our classroom can be seen moving between all four steps of this process, the act of completing the Performing Engineer required that students become particularly cognizant of the first and fourth steps by first identifying the skills that they have transferred and next describing the ways in which these were applied.

Scope

In addition to my role as primary researcher I interact with the study participants in other contexts, through my position as a lecturer in ECP, but also as co-instructor for the course. While I attempt rigour in my data analysis, the collection methods for this study are entrenched within the shape of the course that I have developed with my co-instructor. In this respect, this study and the assignment that it details straddle the realms of qualitative research and classroom methods, as I have gathered and shared student responses to one of my teaching tools and assessment methods. This approach may be seen as complicating the researcher-subject relationship, but it also makes use of a fertile ground for studying the engineering student experience in the liberal arts. In addition, my unique vantage point allows me to develop insights beyond the responses and interviews by making use of my knowledge of disciplinary engineering and communication content from outside my classroom.

This study then is firmly embedded within the field of qualitative inquiry and does not attempt to provide a quantitative analysis of student experience in this class. Indeed, it could be argued that a quantitative approach to this type of research is not only counterproductive but also logistically impossible. Student responses to this assignment are not provided using a numerical scale that would allow for a quantitative categorical analysis; instead, responses are reflective and self-directed. The self-guided nature of these responses accounts for the range of shared transfer points and corresponding categories below; it also contributes to the richness of this discussion.

Methods

All twenty-six students in the class completed the Performing Engineer assignment. This assignment required students to write a five to six page paper identifying at least three points of transfer and describing the activity in which this transfer took place. As noted above they were not provided with a number of options to choose from; the assignment was open-ended. All twenty-six responses were reviewed to generate an inventory of transfer points or skills discussed below. In addition five of these participants took part in a follow-up interview. These interviewees are also participants in the *Engineering and Humanities Intersections* study, for which these interviews were originally scheduled. Each participant's assignment response was re-read in advance of the interview, and in some cases quotes or ideas were drawn from these papers and used to frame additional interview topics. The interviews provided an opportune forum to further discuss ideas introduced in the assignment responses, are a related but separate data point. The interview results are presented separately from the assignment responses within this paper. The discussion section refers to both sources.

A review of written responses identified three broad categories of transfer: approaches to the design process, strategies for effective project management, and communication skills. These general categories were further broken down into subskills as listed below. These categories were generated by the primary researcher who is familiar with class content as well as material and practices from the broader engineering curriculum. To test inter-rater reliability these categories and a five paper sample of responses (17.9% of the overall sample) were reviewed by an ECP colleague, who shares knowledge of the engineering curriculum but is unconnected to this course or assignment. An inter-rater reliability of 89.5% was calculated using Holsti's coefficient [17].

Intersection categories

- *Design process, Problem analysis*: Responses that noted practice or improvement in the ability to analyze, research and respond to a problem, specifically in its early stages, including identifying requirements and/or stakeholders, and goal setting.
- *Design process, Iteration*: Responses discussing iteration and the multiple rehearsals and runs that comprise the rehearsal process.
- *Design process, Ideation*: Responses identifying strategies to aid individual or group brainstorming and decision making in scene work and seminar classes.
- *Design process, Reference designs*: Responses noting the use of research into reference designs or solutions.
- *Design process, General*: Responses identifying overall similarities between design and theatrical creation processes.
- *Project management, Team strategies*: Responses identifying improved team skills and strategies including team communication and group conflict resolution.
- *Project management, Notetaking*: Responses discussing the value of recordkeeping or notetaking (especially in the rehearsal diary).
- *Project management, Work distribution*: Responses focusing on methods to break up and/or distribute work.
- *Communication, Oral*: Responses noting development of oral communication skills or acquisition of strategies to help in communicating orally in formal and informal settings.
- *Communication, Visual:* Responses noting development of visual communication skills.

Results: Written assignment responses

The table below provides the frequency of each category in the Performing Engineering assignment. Some students commented on more than one transfer point or framed a specific strategy as being used in multiple ways, which accounts for the large number of intersections identified (102) in comparison with the number required by the assignment (26*3 = 78).

Table 1. Frequency of identified intersections

Design Process: Problem Analysis	20
Design Process: Iteration	16
Design Process: Ideation	11
Design Process: Benchmarking and reference designs	10
Design Process: Overall	1
Project Management: Team Strategies	12
Project Management: Notetaking and recording	9
Project Management: Planning, work distribution	8
Communication: Oral	13
Communication: Visual	1
Other: Set design and plant design	2

The following descriptions summarize content from all twenty-six assignment responses. As may be evident in these descriptions, students more often articulated methods that they had learnt and could adapt to their engineering work, than they did engineering approaches they had brought to our classroom. In their description of these methods students were often quite specific and direct about the engineering domain (or category) that they saw as improving through this experience.

Problem Analysis: A majority of the students noted that they felt their ability to analyze and respond to a problem in the early stages of the design process had improved. Students discussed these improvements through three techniques used in *Representing Science on Stage*.

The first, a table-read or close reading of a script requires our students to move beyond the literal meaning of a script to analyze subtext by considering the underlying motives of characters, as well as their relationships to others in the scene and their personal history. We introduce this activity to our students early in the semester when we practice the process as a whole group, distributing roles to students and stopping and starting the table-read to ask questions and trigger discussion. Students indicated that they felt this activity had alerted them to the significance of the subtext and the importance of moving beyond a problem statement to consider the underlying needs and wants of the client.

The second activity in this category also relates to analysis of client needs. Some students argued that they could apply their character development to understanding a client's perspective more readily by 'stepping into their shoes'. Students cited a warm-up activity in which they transition from a neutral stance to embody their character's physicality as analogous to embodying the values, wants and needs of a client in industry.

Students also noted the value of discussion based seminars in cultivating analysis skills. Contact hours in this course are divided between two studio hours and two seminar hours per week. While the studio hours focus on scene development and performance techniques, the two seminar hours allow for close discussion and analysis of the themes and subjects of the plays. We rarely lecture in these seminar classes, instead designing activities that encourage students to develop and articulate their own ideas and responses to the texts. Students noted that these activities encouraged them to analyze topics more closely and to consider how to support these observations by identifying supporting materials and arguments in the course texts. This year's plays all focused on one topic, the building of the atomic bomb, which also allowed for many discussions on ethics and decision making in engineering. Some students noted that these types of discussions made clear the potential for a multiplicity of ethical viewpoints, and by extension highlighted the opportunities afforded by multiple approaches to a problem, including engineering design challenges.

Iteration: Many students noted that the format of the course and the structured rehearsal process required multiple iterations. They compared our iterative rehearsal process to iterations in the design process, and specifically highlighted an open-rehearsal activity as an opportunity to prototype early design decisions. The open-rehearsals occurred midway through the rehearsal process, when students had developed their scenes for a few weeks and were ready for external feedback. Each group selected a few minutes from their scene to share with the class and received feedback from their course instructors and their classmates. Many groups used this exercise as an opportunity to work through or 'user-test' performance choices that they were unsure about. In addition to arguing that iteration in both disciplinary contexts was useful for testing design decisions, they also noted its utility within the report writing process. A number of students indicated that the process of receiving peer feedback at multiple junctures in the rehearsal process underscored the value of multiple drafts in an engineering context.

Ideation: Observations about ideation typically focused on seminar activities or group decision making during the scene development process. Like their observations on problem analysis in the seminar classes, some students acknowledged that activities requiring them to identify and share divergent perspectives about issues in a play highlighted the possibility for alternative approaches in other contexts, namely the design process. Many of our class seminar activities began with group brainstorming exercises that provided a useful practice space for these techniques. Some students indicated that they transferred these techniques to decision making while developing their scenes and argued that it could also be used in design projects. Some observations included under ideation were quite novel. One student for example, indicated that she was inspired by the concept of an ideal set design to imagine a best case scenario for her capstone design project before adjusting to existing constraints.

Benchmarking and reference designs: Many students noted the similarity between engineering benchmarking and research for their scene performances. Students indicated that they read biographical information for characters based on real-life people (one of the plays, *Oppenheimer*, explored Robert Oppenheimer's life and friendships at Los Alamos [18]; another, *Copenhagen*, examined the 1941 meeting of Niels Bohr and Werner Heisenberg [19]). They also looked at images of the characters and their contemporaries, and used previous productions to influence their staging decisions. All three strategies were compared to the use of reference designs in the design process

Overall: One student moved beyond individual components of the design process to suggest an overall similarity between design approaches in both contexts, arguing:

> A typical development cycle of an engineering design involves multiple iterations of problem definition, requirements analysis, research, brainstorming, designing, implementation and testing…I have identified similar iterations of stages in the life cycle of a production, such as, brainstorming, background and context research, set design, scene analysis, rehearsals and feedback. [20]

Project management

Students noted that they had developed or discovered techniques that would help them to perform more effectively in future team projects. Many of the skills and approaches discussed in this category were introduced as serving multiple functions in these projects. Notetaking, for example, was discussed by some as both a communication method—a means of expressing concepts to clients—and a strategy for personal organization—a method to keep track of work completed between multiple group meetings or work sessions.

Team strategies: Students indicated that in future they would encourage group cohesion and improve communication and efficiency in their groups by attempting to replicate the strong team bonds that were cultivated in this course. Many students noted that this type of teambuilding would be a challenge to achieve in formal team projects with less opportunity to get to know one another—we purposefully build a number of icebreakers into our early classes that might not be appropriate within a professional project—but they indicated that they would try to develop alternative means of group bonding. One method discussed in multiple responses was the use of team check-ins to reflect upon progress and roadblocks at the end of each meeting. This technique is adapted from our studio circles, where we come together as a group at the end of every studio class so that students can share something that they learnt or that interested them during that session.

Notetaking: About a third of our students noted the value of their rehearsal diary to keep track of their rehearsal process. Some saw it as a useful tool to record research to share with the team; others indicated that it helped remind them of decisions that had been made across multiple rehearsals. Many students suggested that the process of keeping the rehearsal diary helped to highlight the utility of their design notebooks to record their progress on engineering projects.

Work distribution: Students tended to discuss work distribution in two ways. Some students indicated that the process of dividing their script into smaller manageable chunks for rehearsal was analogous to the process of splitting an engineering project into multiple parts. Other students identified strategies for distributing these parts, namely identifying strengths and allotting responsibility based on aptitude. For example, one group selected their designer based on his previous design experience, their actors based on their enjoyment of public speaking, and their facilitator/director based on his previous leadership experience. One student indicated that this approach worked well in our classroom in which 'the stakes are lower' than an engineering classroom, and where individuals are not expected to be subject experts; in this setting they could acknowledge a lack of skill in a particular area and a preference for just one task without 'losing face'.

Communication

Most students discussed communication skills in terms of oral presentations, with just one student discussing visual communication in graphs that she developed to chart characters' emotions. Strategies from the course were seen as supporting oral communication in two ways. First, students noted that relaxation and breathing exercises used during studio classes could be similarly employed before oral presentations and interviews to help foster relaxation, build confidence and produce more effective presentations. A number of students indicated that they had already begun to incorporate these techniques into their preparation for interviews and class presentations. Second, students noted that their work on blocking—their physical positioning on the stage—had made them more aware of the importance of their physicality during presentations and social interactions.

Results: Interviews

Previously scheduled interviews with five participants from the *Engineering and Humanities Intersections* project provided a forum to further investigate ideas introduced within the written responses. While only about one fifth of participants took part in the follow-up interviews they are still a valuable source of information. The written responses from these interviewees were not atypical and discussed most of the transfer skills and sites identified by their peers; it could be inferred that their interview responses are also representative of the general student experience.

Interviewees had self-selected to participate in the *Engineering and Humanities Intersections* project in response to a class call for participants. The group was comprised of three female and two male participants, three from chemical engineering, one from civil engineering and one from electrical and computer engineering. Two of the students were in fourth year, two were in third year and one was in second year.

The distillation and adaption of techniques from our classroom to the engineering context was the primary focus in the interviews, with the format of these discussions allowing students to elaborate on techniques and examples of transfer introduced in their written responses. Given the time that had elapsed between the assignment and the interview—the Performing Engineer was due in November and the interviews took place in January—many interviewees did not readily recall the focus of their written response. Their inability to remember the assignment was actually quite useful as participants often shared new transfer points, before responding to interview questions about those they had identified earlier.

The interview sessions are summarized below. The diagram above the interview summary provides the transfer site or activity originally described in their written assignment, and its transfer or application. The direction of skill transfer is indicated in the diagrams using directional arrows; solid lines indicate direct transfer and a dashed arrow indicates recognition of similarity without a description of transfer or adaptation to the Engineering context. It should be noted that these figures were developed for this smaller sample as a tool to simplify their assignment responses for comparison with the interview content. They have been included here to provide a similar snapshot of the written responses from these five participants.

Participant one [21]

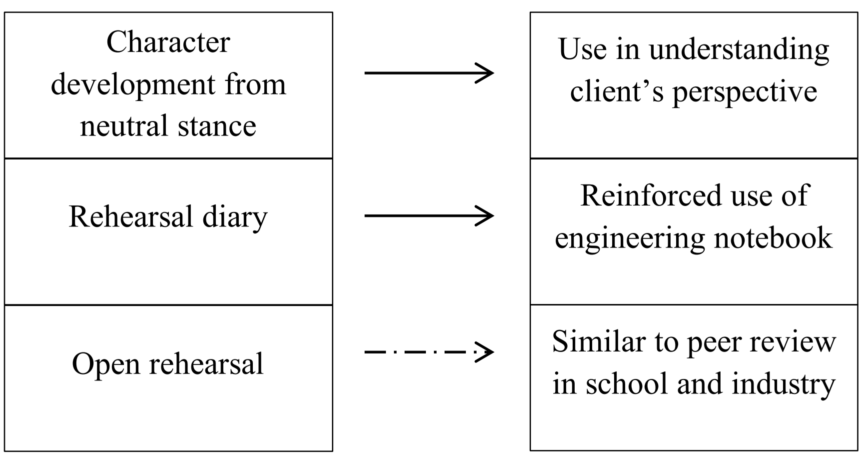

Figure 2. Participant one responses

This interviewee reiterated two of the three strategies reported in her Performing Engineer assignment—the use of a rehearsal diary and the use of neutral stance to understand clients—but spoke in most detail about critical thinking skills and the potential for multiple answers or approaches to engineering problems. She described a common team roadblock as the inability to agree on a solution, and explained that each member thinks: "I know the right answer. Why is this team member arguing with me? I know what the right answer is." In contrast, the need to reach decisions together in our classroom forced the team to become comfortable with compromise, by asking: "What do you see the set being like? What do you see the acting being like? How do you see someone saying this line?" This process, she explained, is not only about acknowledging the possibility of multiple answers and letting go of your belief in just one, but also learning to slow down so that everyone on the team can contribute, but also so that these contributions are more thoughtful. She described her change in attitude as follows:

> You had to learn how to relax and step back a little bit. With a right answer there's always sort of a mad rush…I need to do this. If you read the play and just read the words it's not going to give you much meaning. But, if you sit back and actually pay attention you have to take the time to read everything, and sort of allow your brain to build a picture of what exactly is going on.

This improvement in critical thinking and analysis is one of multiple skills that this interviewee saw as being reinforced through her experience in the course. She suggested that this classroom provided a setting to revisit and practice skills that were introduced formally in other engineering courses, explaining that for many concepts, "we learnt it in engineering but we refined it in *Science on Stage*. We had more time to practice so we got better at it." When asked about the relationship between learning skills in one place and applying them elsewhere, she explained:

> If you get stuck doing it one way and then you try it another way, it helps get you out of the rut you're stuck in…. If I act as someone else and that character is really out there, and I can do that in front of an audience while maintaining composure, then when presenting as myself in front of a PowerPoint or something it shouldn't be that bad.

In this formulation then the *Representing Science on Stage* classroom is seen as a space to practice skills that will later be applied elsewhere in a more relaxed environment.

Participant two [22]

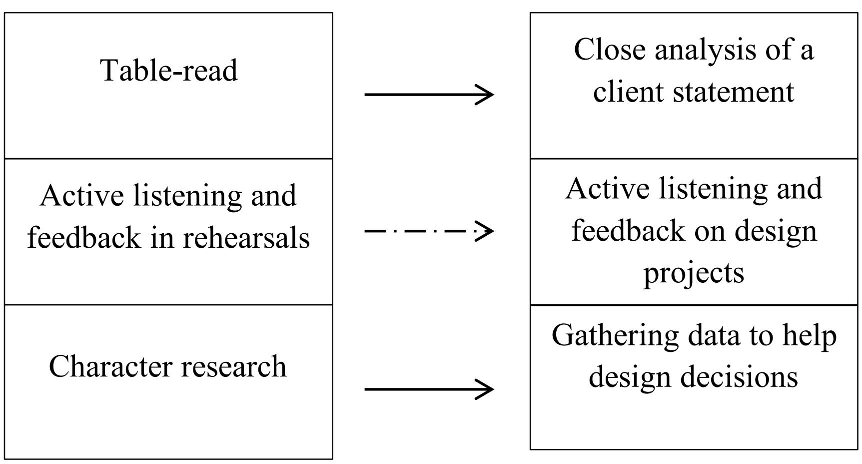

Figure 3. Participant two responses

This interviewee reiterated two of the skills discussed in her Performing Engineer, before expanding the inventory of skills developed, discussing at length the use of group brainstorming and team bonding to boost cohesion and productivity. She delved deeper into observations from the assignment response to argue that doing table-reads and character research helped her to value and improve her audience analysis skills. The importance of understanding one's audience and developing clear characters forced her to spend more time on analysis in our classroom. Her investment in this process, she explained, made evident its value elsewhere:

> We took different avenues to get [to audience analysis than in an Engineering classroom]. There was one [avenue] where we took the open rehearsals, which is like a direct audience, and then there's one where we did like a character development, where instead of just the audience there's a specific person. You get to know the person inside out, and then you're able to be that person. The different techniques that we did to develop the same thing was basically trying to understand the person that you're communicating with, or another person's point of view. And maybe because of those different ways that we took it, it made things more clear, or gave me new techniques that I hadn't thought about before.

This participant is suggesting that her experience in this course increased her awareness of audience from two different angles. On the one hand, performing to an audience made her aware of audience expectations and reception, and the need to shape one's presentation to that audience. On the other hand, the process of analyzing and embodying another character made clear the uniqueness of each individual, and by extension the subjectivity of any audience.

Participant three [23]

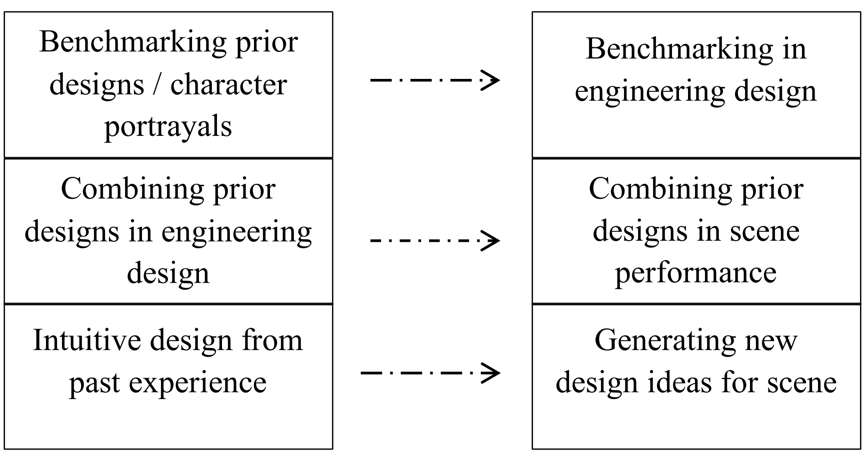

Figure 4. Participant three responses

This interviewee's written response to the Performing Engineer did not focus on his personal skill development, but instead discussed methods and approaches that the disciplines obviously share. In his interview he did not revisit the points of convergence discussed in his assignment, but instead elaborated on performance and the rehearsal process as a strategy for improving communication, suggesting that the amount of time that we devoted to rehearsing the scenes made participants hyperaware of their physicality on the stage and the way that they inhabited space. He described this relationship as follows:

> When you're working on the same scene over and over again you look, and you say: 'you need to be standing two or more steps forward to deliver this with the strength that it needs. Or your movement there is distracting.' And it's a lot more of a practical tool for [you] to visualize what [you're] doing. People try to do it in the communication course. People

stand up, and you say, 'what are you doing with your hands? How are you speaking?' But I think this hit home when you were trying to say someone else's message, and the fact that your body was turned at an angle changes how that message comes across.

This quote compares feedback on his performances in this course to his experience in a required communication course, in which students receive feedback on their physical and oral presentation skills at multiple points in the semester. He argues that the type of feedback shared in both contexts is easier to understand and integrate in a theatre classroom; the act of speaking someone else's lines allows the speaker to focus on the way that words are being communicated because they are less concerned with the content of these words.

This student draws a similar comparison between the process of designing a project from scratch and the process of working to implement an existing design, suggesting that using existing scripts to produce scenes in this course more accurately reflects the professional environment in which engineers design solutions under tightly prescribed constraints.

Participant four [24]

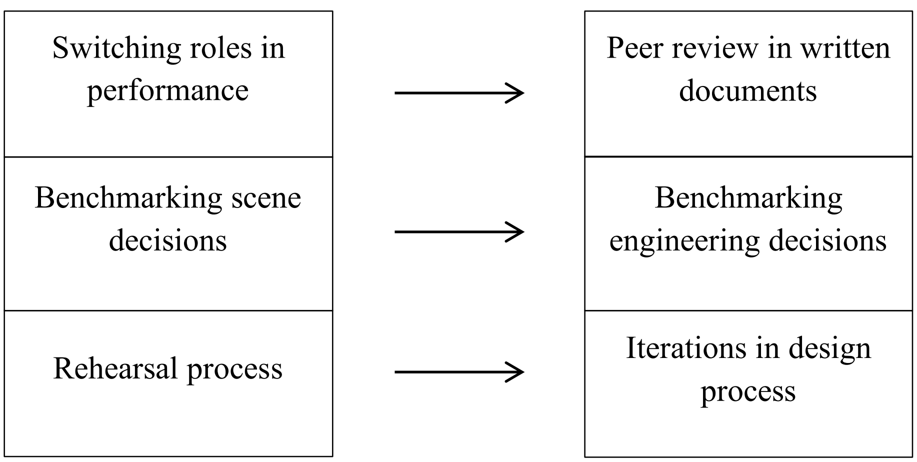

Figure 5. Participant four responses

In his interview this participant clarified the concept of iteration as introduced in his rehearsal diary, and linked his understanding of iteration to the concept of multiple answers or solutions. He argued that the process of iteration taught him the value of patience. He learnt not to rush to a single solution, but to allow earlier approaches to be refined and replaced through the process of iteration. His description here reads quite similarly to participant one's observations:

> I don't really think I was unwilling to change my answers [previously] I think it was just I was confident that I could get a very good result on my first answer. But, this course has shown me that if you really want to do well you need to invest your time in something and go over it and analyze it in different ways; change little things to see how they work. In doing my first APS111/112 [first year design] projects a lot of our documents were written in one or two goes and then maybe a rewrite or an edit at the end and then we did very poorly and we couldn't figure out why. So, after this course, if I could go back and do that

> I would definitely have a first draft, scrap it, have a second draft, edit that one, scrap it, have a third draft.

While this participant acknowledges the importance of iteration, he also notes the significance of the class structure and organization in facilitating this iteration. By focusing on a ten minute scene performance for an entire semester students are forced to continually improve, and this contrasts sharply with larger engineering projects that need to be produced in a shorter time frame. Despite these differences however, this participant was still confident that he could effectively utilize iteration in a compressed timeframe, noting: “Before I would say that iterations aren’t important and that it’s better to just get it done and do your best the first time, but I think this course has shown me that it’s important to iterate. So, don’t just stop.”

Participant five [25]

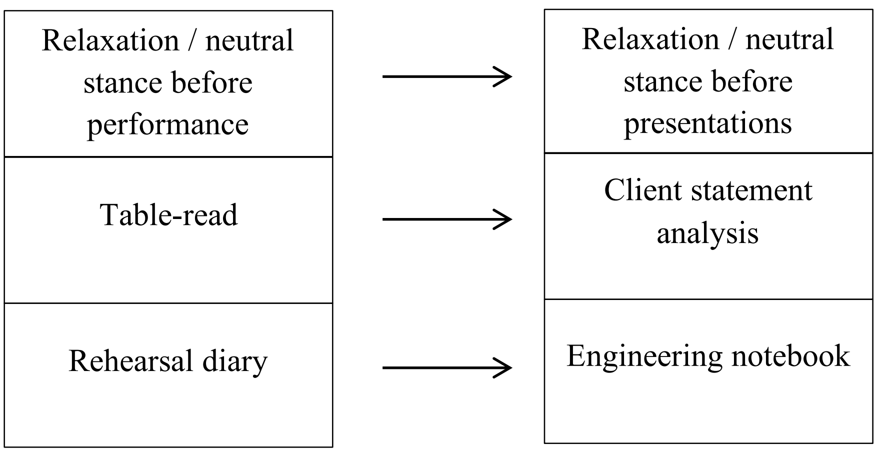

Figure 6. Participant five responses

The type of transfer that this participant focused on in her interview had little to do with the activities or skills discussed in her written response to the Performing Engineer. Instead, this participant talked at length about the value of seminar discussions and studio activities in illustrating the possibility for many answers or perspectives. She described her response to this multiplicity of answers or approaches as follows:

> What I learned is that even though Engineering is completely different from other fields, it doesn’t necessarily mean that there always has to be a right or a wrong answer…And that’s kind of what frustrated me when I started university. I was kind of like, there’s always a right or wrong answer, so no matter how hard I try, right, there’s always—at the end of it I’m always going to get it wrong or right. So I would always think, “With this problem, I need to know how to approach it first. So, what am I even supposed to start thinking about?’ And I always used to think, ‘If I don’t even know which way to start thinking about this problem, I’m just going around in circles.’ And I think what helped me about this course is that we talked about it: is there always a right or wrong answer? In performance there’s not most of the time…You know you can brainstorm to whichever way you approach it, like it’s not necessarily going to be wrong. So I think that can also be applied to engineering. Because, though there might be a right or wrong

> answer it doesn't always have to be the case—you could still approach it from another way and get the right answer. Or approach it from another way and get an answer that maybe someone has never thought about. And that's helping me, especially in my capstone.

This student is making an interesting connection between the multiple perspectives shared in our classroom activities, and the possibility for multiple approaches to engineering and design challenges in her other courses. Later in the interview she noted that she had been encouraging her group for a capstone project to look beyond the most obvious 'engineering' problems and solutions to uncover latent issues and non-obvious approaches. Her experience in this course contributed to this student's epistemological development in both disciplines, as she had developed an understanding and acceptance of multiple perspectives.

Discussion

There are a few recurring themes that standout in written responses to the Performing Engineer assignment and the interviews. First, students noted that they discovered the value of analysis and the importance of reading beyond the text to identify underlying needs and motivations within a problem. Second, students indicated that the course made them more aware of the value of iteration and the importance of multiple drafts in the writing process, as well as the potential to design and prototype alternative designs within the design process. Third, students reported an improvement in their oral presentation skills through the use of relaxation and focus exercises, or through increased awareness of body language and physicality. And finally, students suggested that elements of their positive team experience could be transferred to team situations in their technical courses. These perceived transfer points neatly align with two of the three outcomes attributed to liberal arts opportunities for engineers: improved communication and teamwork skills. While students did not introduce the issue of comfort in cross or interdisciplinary settings within their written responses, the topic came up as a point of discussion in the interviews. Three of the five interview participants noted that their participation in this course made them more open to selecting additional non-technical electives in their second semester.

Notably, many of the specific communication, planning and iteration strategies that the students discussed are formally instructed in other parts of the curriculum. Interviewee three compares his experience in this class to a second year communication course in Chemical Engineering that approaches oral presentation instruction through an iterative approach. Interviewee four compares it to a pair of first year design and communication courses in which students follow prescribed ideation and decision making techniques as well as an iterative writing process. Both students can recognize and analyze the learning outcomes and strategies in these courses using the insights gained through participation in this course and reflection within this assignment. In both cases the interviewees suggest that they learnt and retained concepts more effectively through this course experience than their experience in the other courses, where iteration and ideation techniques were a central pedagogical focus. In other words, these two students retained less when particular skills were a privileged outcome rather than one of multiple tools that they brought to the experience. Perhaps this site, where processes and actions are decontextualized and where students determine their use helped to underscore or reinforce behaviours more formally taught within other Engineering Communication classrooms.

For the purposes of this discussion it is important again to acknowledge my position and role outside of the *Representing Science on Stage* classroom and within the larger curriculum. Of the five students who participated in the follow-up interviews, one is in Civil Engineering, one is in Electrical and Computer Engineering and three are in Chemical Engineering. The class as a whole is made up of a fairly even mix of students from Chemical, Civic, Electrical and Computer and Mechanical and Industrial Engineering. As the communication coordinator for Chemical Engineering I am responsible for the planning and delivery of most communication content across the curriculum; in this capacity I coordinate communication courses, plan and oversee some core-course projects, and provide individual assistance to students requiring communication support. In fact, I plan and coordinate the course that participant three sees as failing to effectively instruct iteration. While I am not formally involved in Civil, Electrical and Computer or Mechanical and Industrial Engineering, I am familiar with the content covered by my communication counterparts embedded in these departments, and the material covered within their lectures, tutorials and various interventions. As a result, as the students in the study articulated their perceived outcomes from this course, I could compare the effect that they saw occurring in our classroom with the anticipated outcomes for our formal communication instruction in the other courses. Their observations during the interviews could isolate and acknowledge the limits of certain pedagogical approaches within a typical communication classroom.

According to multiple participants, one reason for their improved understanding within our classroom was the limited number of deliverables and the extended timeline for completion of these deliverables. While participant four discussed this most directly, all of the interview participants and many of the written responses acknowledged that the extended timeframe, with groups working on a single short scene for seven weeks of the semester, made them more aware of their own iterative process and the impact of incremental improvements on their project. This timeframe also discouraged the type of rushed team environment that might lead students to arrive prematurely at one solution or approach; instead, students had the freedom to participate in careful analysis and discussion, which allowed them to contribute to a project that they were invested in. Iteration and analysis in this context both require and encourage reflection from our students, as they learn to ‘sit back’ and think before delving into a project, instead of missing opportunities or repeating old mistakes. This slower pace may facilitate the knowledge transfer model by giving students the time to identify the skills worth transferring (knowledge awareness) before adapting and applying these within their new context. The fact that these skills are selected by our students suggests that they are seen as valuable and useful even when they are not explicitly encouraged by the instructor. The act of adapting and applying these in a new space gives an additional opportunity to practice the skill and improve retention.

While we may argue for the success of the course in promoting knowledge transfer it is also important that we acknowledge the role of the assignment itself in promoting a greater awareness of the mechanisms involved in this transfer. By asking our students to reflect upon their interdisciplinary exchange we both assumed that this occurred and encouraged purposeful bridging between the two fields. While this type of metacognition may ultimately benefit our students the associated data is not completely neutral or representative; our students necessarily identified and discussed interdisciplinary transfer points to succeed in the assignment.

Conclusion

The Performing Engineer assignment and follow-up interviews provide two data points through which to explore the intersection of Engineering and the Humanities, and the unique learning that occurs at these junctions. By reflecting on the *Representing Science on Stage* classroom our students could identify skills that they might transfer and could describe how they would go about doing this. Organizational factors of the course as a whole—notably the extended timeline and embedded iteration—supported the development of some key skills associated with the outcomes of a liberal education, namely improved communication and teamwork skills. Whether similar responses could be generated in other contexts will be the focus of ongoing research (in the *Engineering and Humanities Intersections* project), but even outside of a liberal arts classroom the types of instructional approaches shared here may contribute to creating an environment that fosters deeper analysis, reflection and iterative learning.

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