Enhancing Engineering Education through Transfer of Learning, Authentic Assessment, and Engineering Simulations

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The transfer of learning focuses on the ability to apply knowledge and skills acquired in one context to solve problems in different, often real-world, situations [1], [2]. Facilitating this transfer is essential for preparing students to effectively enter their workplace [3]. This is especially relevant in the field of engineering as there may be gaps between academic and on-the-job information. However, discussions on how students carry knowledge, skills, and attitudes (KSA) from one module to another, and the research on the transfer of learning focused from school and work contexts are largely unexplored [4].

Studies have uncovered some key elements on effective transfer of learning. These elements include: (i) Teaching "big ideas" and guiding students to conceptually view connections in different contexts, (ii) Practising skills with real-time feedback, (iii) Application of skills and knowledge in ill-structured problem solving situations, (iv) Opportunities to practice skills learned in school in the context of work, (v) Scaffolding learning activities to build up from specific skills to application of those skills in different environments, and (vi) Support from instructors/supervisors, an explicit expectation of transfer, and a value of transfer [5], [6], amongst others.

Authentic assessments are practical assignments that mirror the complexities of engineering practice. This complements the transfer of learning by evaluating students' knowledge and develops their ability to apply it effectively beyond their textbooks. Elements of authentic assessments that promote the transfer of KSAs have been theorized [7] but require further examination. Simulation-based learning has been applied to enhance education of various disciplines and prepare students to undertake critical decisions, especially in engineering [8] – [10]. As a form of experiential learning, engineering simulations further provides a wide range of opportunities to practice complex skills in higher education to facilitate effective learning [11]. Like authentic assessments, simulations have the potential to enhance the transfer of learning by providing students opportunities to explore real-life conditions and test their ideas in a simulated environment.

In part of a more comprehensive study, this paper will integrate authentic assessments and engineering simulations to enhance the transfer of learning in engineering education. One of our research questions is "*How can teaching be redesigned to support students in applying knowledge and skills in real-world problems?"*

Literature Background

To understand how knowledge and skills can be applied from foundational modules to projects with a real-world context, the transfer of learning must be scrutinized. As such, any changes to education or teaching must incorporate an understanding of the transfer of learning to better support students. The study of transfer aims to determine to what extent training, or an educational background, encourages learning that can be applied effectively and continuously in a work context [12]. There are 3 stages of transfer of learning [2].
1) In the first stage, the inputs to training, including the trainee characteristics, training strategies and the work environment are defined.
2) In the second stage, through the training process, these inputs generate training outputs in the form of learning and retention.

3) In the final stage, transfer of training occurs when learning and retention are generalized and maintained in the work environment.

The US National Research Council's (NRC) evidence-based approach to assessing for transfer [13] states that the assessment rests on three pillars that need to be closely synchronized. Three major characteristics of an authentic assessment summarized by [14], processes, tasks, and outcomes, are closely related to the NRC's three pillars of evidence-based approach to assessing for transfer, as shown in *Table 1*.

Table 1. Pillars of Assessing Transfer and Characteristics of Authentic Assessment

Three Pillars of Evidenced-based Approach to Assessing for Transfer [13]	**Three Characteristics of Authentic Assessment that Enhances Transfer of Learning [14]**
A model of how students represent knowledge and develop competence in a domain	**Processes** ● Required performance criteria provided beforehand ● Evidence of competence to be collected by the student
Tasks or situations that allow one to observe student performance relative to the model	**Tasks** ● Set in a real-world context ● Requiring an integration of competence ● Comprising of forward-looking questions ● Ill-structured problems
An interpretation framework for drawing inferences from student performance	**Outcome** ● Higher student engagement ● Ability to transfer context in different fields ● Contextual and multiple evidence of competence ● Validated and reliable student performance

To answer the Research Question, teaching can be redesigned to support students in transfer their knowledge and skills by integrating the transfer of learning and authentic assessment concepts displayed in *Table 1*.

Methodology

Based on an undergraduate engineering program at the Singapore Institute of Technology, students are exposed to simulations using finite element analysis (FEA) and computational fluid dynamics (CFD) as part of their Year 1 engineering foundation [15], [16]. In Year 2, the students are taught the Mechanical Simulation (M&S) module to learn how to solve ill-structured problems [17].

For this research study, an intervention was developed within the M&S module to improve the transfer of learning ability of students. The key elements of transfer of learning and authentic assessments identified in the previous sections were built into this intervention. The main features of the intervention were:
(1) An ill-structured task as a graded module requirement – Students were given various real-life engineering problems to solve using simulation tools as an authentic assessment.

(2) Awareness for the need to transfer learning – Students were made aware throughout the M&S module (such as in lectures and consultation sessions) that they had to use relevant information from past modules to solve the task given in (1).
(3) Reflection section on linking existing information – Students had to reflect on what sort of existing KSAs they had used to solve the task given in (1). They then orally presented this reflection.

The students are evaluated before and after the M&S module to ascertain the effectiveness of the intervention in an online survey and hence, determine their needs for transferring learning.
(a) A 14 item Transfer of Learning Questionnaire (TLQ) adapted from [18], provided pre- and post-intervention, measures student perception of the importance, ease, and potential obstacles to transfer. This questionnaire is composed of three constructs – attitudes to transfer, barriers to transfer, and learning retention. All 14 items are rated on a standard Likert scale from 1 (Disagree) to 5 (Agree), with option 3 (Neither agree nor disagree) being neutral.
There are also the following evaluations underway, where a more comprehensive analyses will be submitted in the full paper.
(b) The Basic Psychological Need Satisfaction and Frustration Scale (BPNSFS), provided before the intervention, measures students' self-perceived characteristics and motivation in relation to their levels of autonomy, relatedness, and competence [19].
(c) The Problems in School (PIS) Questionnaire [20], provided before the intervention, measures their orientation towards decision-making, either being more controlling or more autonomous.
(d) An Ill-Structured Problem Validation Tool (ISPVT) [21], provided after the intervention, allow students to validate if the graded task is ill-structured and perceived as close to an authentic assessment.

As this is a Work-In-Progress research paper, only the results and a brief analysis of evaluation (a) will be included in the following section. A paired sample t-test is conducted to identify any significant differences between the students' pre- and post-intervention scores for evaluation (a). Subsequently, this project aims to conduct a longitudinal study and evaluate the abilities of the students in their internship programme, where they will work in the engineering industry full-time for eight months. The benefits and challenges of transferring KSAs in an actual work environment are further investigated. Using this additional data, the elements of authentic assessments that can enhance the transfer of learning in engineering education can be identified as well. After all, students experiencing industries such as engineering design process and manufacturing that require a mechanical engineering skillset may be transferring their learning from their Year 1 and 2 modules.

Results & Discussion

After the recruitment of the undergraduate engineering program of 126 students, removing incomplete responses, and pairing the remaining students, a sample of n=79 is left. Their statistical means are shown in *Table 2*, along with the respective p-values under the post-intervention scores. A significant difference in means was observed in items 1, 2, 5, 10, 11, and 14 (p<0.05), while the remaining items had no significant differences. Despite the lack of significance for all items in the questionnaire, a few trends on the elements of transfer are apparent.

Table 2. Results of the TLQ (n = 79)

No.	***Questionnaire Items***	***Pre-Intervention***	***Post-Intervention (p-value)***
Attitudes to Transfer			
1	I can connect the material learnt in the M&S module with other modules.	4.03	4.20 **(<0.05)**
2	I often think about how to relate the M&S module topics with other modules topics taught in this degree programme.	3.80	4.16 **(<0.05)**
3	It is important to relate materials from the M&S module with materials from other modules in this degree programme.	4.20	4.22 (0.40)
4	It is easy to use or apply material from other modules into the M&S module.	3.84	3.95 (0.16)
5	I expect to make connections from one topic to another within the M&S module.	4.10	4.29 **(<0.05)**
6	I expect to make connections between different modules in this degree programme.	4.16	4.25 (0.19)
Barriers to Transfer			
7	The material from other modules is relevant for the M&S module.	4.13	4.22 (0.19)
8	I focus my efforts on what the Professor wants in the M&S module.	4.15	4.27 (0.11)
9	I don't know the materials from other modules well enough yet to apply in the M&S module.	3.13	3.29 (0.19)
10	I don't like to think that hard to transfer the knowledge from other modules to the M&S module.	3.29	3.63 **(<0.05)**
11	Transferring knowledge from other modules to the M&S module might confuse students.	3.09	3.59 **(<0.05)**
12	I don't have time to refer to knowledge in other modules for the M&S module.	3.08	3.16 (0.32)
Learning Retention			
13	Do you think pre-training in the use of computational tools is useful for the M&S module?	4.16	4.27 (0.20)
14	How confident are you in using computational tools for problem-based assessments in the M&S module?	3.51	3.78 **(<0.05)**

Attitudes to Transfer

A slight improvement can be observed in the students' attitudes towards transferring learning, with all post-intervention results showing an increase in items 1 to 6. Firstly, the students felt that they were able to connect what was learned in the M&S module to other modules, as seen in the results of item 1. Such an outcome may have indicated a belief in their ability and competency to use information from the M&S module and apply it elsewhere. Item 2 displays a similar result. Students often thought about how to relate their learning more than prior to the intervention. Aspects of the intervention may have played a strong role in their perception; by raising awareness on the need to transfer learning, students would have more consciously considered how the M&S module interconnects with other modules they had learned previously. Thus, the process of "how" to transfer becomes further ingrained in their studying habits as they navigated the M&S module, shifting their behaviour and attitudes towards transferring learning post-intervention.

In contrast to the previous two items, the students' ratings on the importance of transferring learning, as observed in item 3, remained unaffected. This result was surprising as the need to transfer was heavily emphasized as part of the intervention, which ideally would enhance their perception towards the importance to transfer learning. Yet, it was not sufficient to affect their overall attitude, indicating that the existing intervention strategy was incomplete. Regardless, the students maintained a favourable view of the importance of transfer after the M&S module, supporting the idea that their expectations were not negatively impacted by the intervention. Lastly, there were mixed findings for items 5 and 6. By the end of the intervention, students were expecting themselves to make more connections within the M&S module than to make connections between different modules in their degree programme. Although the intervention led to a positive effect specifically for the M&S module, this did not extend to other modules the students were taking. One possibility for this could have been due to the generic wording of item 6, as students might have viewed the intervention as taking place within the M&S module, compared to other modules they were taking in the same academic term. Hence, they would have placed more emphasis on studying for the M&S module only. A further examination of the upcoming surveys and interviews may provide a further insight.

Barriers to Transfer

With regards to the barriers to transfer construct, all the results from items 7 to 12 were unexpected. Based on item 9, although not statistically significant, the students indicated that they understood the materials in the M&S module less than when they started the module. Items 10 and 11 further highlights the students' struggles when undertaking the module and intervention programme. The students preferred having an easier time trying to transfer knowledge from other modules to the M&S module, as well as thought that carrying out such a transfer would cause some confusion. With the inclusion of the intervention, students had to put in additional effort in revisiting previous modules to transfer learning, along with paying more attention to their other current modules. This could have been more academically demanding, leading the students to work harder because of the new requirements to complete the ill-structured graded task and reflection segments.

With the increase in post-intervention scores from items 9 to 12, it is likely that there is a minimum level of both competence and effort needed to transfer learning; Competence in fully understanding previous modules, and effort in studying the M&S module in tandem with previous modules. It is likely that most students found these to be significant barriers to transfer learning, despite the results of item 1 and 2 supporting that they can transfer learning and were thinking about it more. Again, a deeper understanding of how students perceive this minimum level of competence and effort as a substantial barrier can be reported after completing further longitudinal study.

Implications of the Intervention

Based on the preliminary results, the intervention has a positive effect on the students' attitudes to transfer while having a negative effect on their barriers to transfer. To partially answer our Research Question, this intervention tool is not yet ideal to redesign engineering education. However, it is too early to conclude what the implications of such a tool are on the students' ability to transfer KSAs from one module to another, as there are many issues left unanswered. As mentioned above, having the students consciously transfer what they know

from prior modules could academically challenge them more than usual; Any intervention of a similar nature might face the same problem. A student having an improved attitude to transfer could find it harder to transfer what they know, thus creating more barriers. The balance between these two elements is a topic that is without a doubt important and needs to be explored further. Ultimately, this intervention makes for a good starting point to increase the transfer of learning behaviours in engineering students.

Future Directions (Work-in-Progress)

Moving forward, this research plans to conduct multivariate analysis to measure the correlation between the students' psychological needs scores (BPNSFS), orientation towards control and autonomy (PIS), characteristics of the authentic assessment (ISPVT), and the results of the TLQ. These sources of quantitative data measure self-perceived characteristics and motivation, decision-making orientation, and the quality of an authentic assessment respectively, which may have an impact on how students transfer their learning. This will be supplemented by qualitative data in the form of student interviews and focus group discussions once they have completed their internship programme. The open-ended nature of qualitative data will be beneficial in verifying how teaching can be redesigned to support students in practicing the transfer of learning. Finally, using the preliminary results from this paper, several other topics of interest can be further explored, such as the perception of the importance in transferring learning from the classroom to the workplace, as well as other unidentified difficulties in bridging the school-work gap, after students have had their internship.

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