

## **The importance of doing rather than discussing: how curricular changes affected student design-task prioritization in a hands-on design project**

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## **Abstract**

The Global Leadership Program (GLP) is a component of collaboration between Massachusetts Institute of Technology (MIT) and Singapore University of Technology and Design (SUTD). During GLP, a design-based wilderness education class addresses the development of design thinking, engineering science, and leadership skills; it consists of project-based classroom and shop activities on campus, followed by a multiday wilderness expedition. After the 2015 class, students tended to place increased importance on tasks related to immediate action such as building. At the same time, decreased importance was placed on exploratory tasks such as understanding the problem and iterating. The 2016 curriculum was modified with these findings in mind, increasing the time spent discussing exploratory aspects of the design process and increasing the number of opportunities for students to iterate on designs. Spending more time just discussing a specific design task (understanding the problem) was not associated with students continuing to emphasize its importance. However, we found that spending time performing a specific design task (iterating) was associated with students continuing to emphasize its importance.

## **Background**

Since 2010, Massachusetts Institute of Technology (MIT) has been collaborating with the government of Singapore to establish the Singapore University of Technology and Design (SUTD). This ongoing partnership focuses on curriculum development, faculty training, collaborative research, and the development of SUTD's student culture. Focused on student culture, the Global Leadership Program (GLP) takes place each summer on and around MIT's campus. Approximately 40 students from the two universities are brought together to interact with the MIT community and experience MIT's academic environment. GLP consists of a series of classes to develop leadership and engineering competencies. Students participate in classes on leadership, communication, ceramics, architectural drawing, globalization, and design.

One of the classes associated with GLP employs design-based wilderness education pedagogy. The curriculum used in this class was developed to holistically address the development of design thinking, engineering science, and leadership skills; it consists of classroom and shop activities on MIT's campus, followed by a multi-day wilderness expedition. This design class uses the unique prompt of a wilderness expedition to have students design solutions to problems associated with wilderness travel, using the products they designed and built while on a multi-day wilderness expedition.

In 2015 a pre- and post-assessment was given to students immediately before and shortly after participating in the design-based wilderness education class. The assessment consisted of an inventory of 23 activities associated with the design process; students were asked to identify the six most and the six least important activities. This inventory

was used to help understand the learning outcomes students associated with the design class.

After the 2015 class, we found that students tended to place increased importance on tasks related to immediate action such as building. At the same time, decreased importance was placed on exploratory tasks such as understanding the problem and iterating<sup>1</sup>. This was contrary to our expected results. As we will discuss in the following sections, the curriculum was originally developed with the intention of emphasizing the importance of understanding the problem and iterating. The 2016 curriculum was modified with the 2015 findings in mind, increasing the time spent discussing exploratory aspects of the design process and increasing the number of opportunities for students to iterate on designs.

To evaluate the effects of these changes, the 2016 participants were given the same pre- and post assessment. On the post-assessment, students were additionally asked to explain why they selected one of the activities as most important and one of the activities as least important. This study considers if the curricular changes were effective in impacting students' perception of the engineering design process at the end of the program.

### **Design Based Wilderness Education Pedagogy**

The wilderness environment was chosen as the design project prompt as learning outcomes associated with wilderness education, such as leadership, teamwork, self-confidence, and communication<sup>2</sup>, are among the attributes and characteristics called for by the National Academy of Engineering in the Engineer of 2020 report<sup>3</sup>. Supporting GLPs goal of exposing students to MIT's academic culture, wilderness education programs are also more effective at helping students transition into new academic cultures than traditional orientation programs<sup>4</sup>. A unique advantage of wilderness education programs is that "the effects of adventure programs continue to increase over time, and are maintained over considerable time"<sup>5</sup>.

Design-based learning and wilderness education are both rooted in the experience based educational philosophy of John Dewey<sup>6</sup>. Dewey argued that all learning takes place in the context of a social and physical environment, building on previous experience. Design-based learning curricula are structured around students developing personally meaningful artifacts<sup>7</sup> that "make their understandings visible to others"<sup>8</sup> while applying an engineering design process<sup>9</sup>.

Building on these connections, the wilderness environment is a particularly apt location to consider Schön's notion of design thinking as a process of reflection-in-action<sup>10</sup>. As described by Dym et al., design thinking "reflects the complex processes of inquiry and learning that designers perform in a systems context, making decisions as they proceed, often working collaboratively on teams in a social process"<sup>9</sup>. Designing in and for a wilderness environment is intended to provide the "surprises, pleasing and promising or unwanted" that would encourage students to respond as reflective practitioners to design-based learning prompts<sup>11(p56)</sup>.

## Curriculum Development

The design-based wilderness education curriculum consisted of a series of lab and classroom activities that prepared students for a 4-day sea kayaking expedition off the coast of Maine. The curriculum was developed using the Teaching for Understanding Framework which focuses on the development of generative topics, understanding goals, performances of understanding, and on-going feedback<sup>12</sup>. Wilderness education components of the curriculum were based on best practices from Outward Bound<sup>13</sup> and the National Outdoor Leadership School<sup>14</sup>.

While on campus students were challenged to think about problems through an engineering science lens, identifying the underlying scientific principles governing problems they were trying to solve. As an example, students were introduced to clothing layering systems as a heat transfer problem, quantitatively exploring the science behind the saying of “cotton kills”.

The main design project students participated in on campus was designing and building a single-burner alcohol stove. Students then used their stove to cook all their meals while participating on a 4-day wilderness expedition.

The design process followed by students is a truncated version of the spiral (or iterative) product design process<sup>15</sup>. Students are presented with specific problems such as making a stove, or building a shelter, and therefore do not have to spend a lot of time identifying a need, defining a problem, or performing market research. Similarly students do not have to consider issues at the end of the process such as manufacturability or product lifecycle. This abridged process is reflected in our finding from 2015 that, after participation in the course, students were less likely to identify understanding the problem as one of the most important design tasks<sup>1</sup>.

In response to this finding, the 2016 curriculum was modified to increase emphasis on understanding the problem before beginning to build anything. Originally students were provided the design prompt (make a stove) and permitted to proceed in whatever way they saw fit without much in the way of instruction. When introducing the stove project on campus in 2016, the instructors first spent an hour exploring concepts associated with combustion to better understand both the technical aspects involved with building a stove, and other ways in which people have solved the problem of cooking in the back country. Students were also encouraged to generate a list of technical requirements before starting a design. These changes were made as understanding the problem is a core competency that engineering education is meant to address<sup>9</sup>.

The second surprising finding from the 2015 program was that students were also less likely to regard iterating as one of the most important design tasks after participating in the program<sup>1</sup>. The stove design activity had been chosen specifically as it provided the opportunity for students to engage in rapid prototyping. With limited experience a working stove could be made in as little as 15 minutes. Students had the opportunity to

build multiple stoves while on campus over two shop sessions. We envisioned that by working on small projects that allowed for rapid prototyping and many iterations the cyclical iterative nature of the engineering design process would be highlighted<sup>15,16</sup>.

Some students may not have had enough time to iterate during the two on-campus sessions. To give students more opportunities to iterate in 2016, tools and extra materials were available during the 4-day sea kayaking expeditions so that students could build new stoves after the trip had begun. While some students used the stove they brought for the entire trip, others took advantage of the opportunity to build new stoves after gaining experience using their original designs in the wilderness environment.

## **Methods**

The 45 participants of GLP in 2016 were invited to participate in a study investigating the potential of design-based wilderness education as an educational approach. Thirty-four (76%) of the students enrolled in the study. Of the enrolled students, 23 (68%) identified as male and the remaining 11 identified as female. Twenty-seven (79%) of the students were from SUTD, and the remaining seven were from MIT.

The students from SUTD have all completed an intensive project-based introduction to design class and are half way through their sophomore year. Singaporean men are required to complete two years of national service before starting university, resulting in most having camping experience through jungle-warfare training programs. Many of the students from SUTD also participated in wilderness education programming through Outward Bound Singapore while in high school. The MIT students were almost all sophomores with a range of design experience. Most of the MIT students were unfamiliar with the wilderness environment.

A survey was given to assess the impact of the design-based wilderness education module on students design thinking. Pre- and post- assessments were given to participants immediately before and after participating in the design-based wilderness education module. The assessment consisted of an inventory of 23 activities commonly associated with the engineering design process. Students were asked to identify the six most important and the six least important design activities.

This inventory was developed by Mosborg, Adams, and Kim as a component of a study exploring expert perception of the design process and changes in student perception of the design process over time<sup>17</sup>. It is based on an earlier question developed by Newstetter and McCracken<sup>18</sup>. The 23 activities were listed in alphabetical order and are not necessarily mutually exclusive from each other.

Of the twenty-three design activities below, please put a check mark next to the SIX MOST IMPORTANT

- ☐ Abstracting
- ☐ Brainstorming
- ☐ Building
- ☐ Communicating
- ☐ Decomposing
- ☐ Evaluating
- ☐ Generating alternatives
- ☐ Goal setting
- ☐ Identifying constraints
- ☐ Imagining
- ☐ Iterating
- ☐ Making decisions
- ☐ Making trade-offs
- ☐ Modeling
- ☐ Planning
- ☐ Prototyping
- ☐ Seeking information
- ☐ Sketching
- ☐ Synthesizing
- ☐ Testing
- ☐ Understanding the problem
- ☐ Using creativity
- ☐ Visualizing

**Figure 1 Example of Design Question Wording**

An example of the format of the design question is given in Figure 1. On the post-assessment students were also asked to “choose one design activity you identified as most important and explain why you selected it”. Students were asked to do the same for another design activity that they identified as least important. These responses were openly coded and analyzed through a constructivist grounded theory perspective<sup>19</sup>.

This paper explores the differences between the pre- and post-assessment results of the 2016 GLP. We compare the results to those of the 2015 students, in light of the curricular changes that were made in 2016. The students responses to the written question provides context for their answers, along with instructor observations. The students are not being compared to an objective standard. Rather, student responses provide a proxy indicator of the learning outcomes of the students that can be compared to the learning outcomes of the curriculum as designed.

## **Results**

As displayed in Table 1, when asked to identify the most important design tasks, four of the top five responses remained consistent between the pre- and post-test. Understanding the problem, communicating, planning and identifying constraints all continued to most commonly be regarded as important before and after participation in the class. In the post-test brainstorming was replaced by making decisions.

**Table 1 Top 5 responses by students asked to identify the MOST important design activities (2016, n=25)**

MOST important before 2016 design-based wilderness education		MOST important after 2016 design-based wilderness education	
Statement	% Students	Statement	% Students
Understanding the Problem	92%	Communicating	76%
Communicating	60%	Understanding the Problem	64%
Brainstorming	60%	Identifying Constraints	48%
Planning	52%	Planning	40%
Identifying Constraints	52%	Making Decisions	36%

**Table 2 Top 5 responses by students asked to identify the MOST important design activities (2015, n=28)**

MOST important before 2015 design-based wilderness education		MOST important after 2015 design-based wilderness education	
Statement	% Students	Statement	% Students
Understanding the Problem	93%	Understanding the Problem	64%
Prototyping	61%	Communicating	61%
Communicating	57%	Making Decisions	54%
Brainstorming	46%	Seeking Information	43%
Making Decisions	43%	Prototyping	43%

Students were less uniform in their opinions on the post-test with only communicating seeing an increased number of students identifying it as most important. While the remaining tasks all saw decreases, understanding the problem saw a large decrease of 28%.

Five students provided an explanation for selecting communicating as most important. The students had differing motivations, mentioning the importance of being able to explain your own ideas, improving teamwork and collaboration, and communicating with users. Three students provided an explanation for selecting understanding the problem with one student stating, “reframing and defining the problem and the assumptions is important because you don't want to work on long projects and realize that it doesn't solve the root cause of the problems.” Four students explained their choice of identifying constraints agreeing that, “knowing your limitations allows the team to innovate under the given circumstances better” and “[identifying constraints] defines the boundaries of your ideas and their alternatives”.

Table 2 presents the 2015 program results<sup>1</sup>. The decreased proportion of students identifying understanding the problem as most important is almost identical to the 2016 survey results. Communicating saw a much smaller increase in 2015. Three of the top five responses in the post-survey remained consistent between years: understanding the problem, communicating, and making decisions. While more consistent within years, the rank-order of the most common responses is also fairly consistent between years.

**Table 3 Top 5 responses by students asked to identify the LEAST important design activities (n=25)**

LEAST important before design-based wilderness education		LEAST important after design-based wilderness education	
Statement	% Students	Statement	% Students
Abstracting	76%	Abstracting	96%
Making Trade Offs	72%	Decomposing	68%
Decomposing	56%	Modeling	44%
Visualizing	52%	Sketching	44%
Sketching	40%	Visualizing	44%

**Table 4 2015 top 5 responses by students asked to identify the LEAST important design activities (n=28)**

LEAST important before design-based wilderness education		LEAST important after design-based wilderness education	
Statement	% Students	Statement	% Students
Sketching	68%	Abstracting	75%
Abstracting	57%	Sketching	57%
Imagining	50%	Decomposing	46%
Decomposing	46%	Synthesizing	43%
Making Trade Offs	43%	Goal Setting	43%
Goal Setting	43%	Imagining	43%

Table 3 displays the activities most commonly selected by students asked to identify the least important design activities. Before participating in the design-based wilderness education program students most commonly selected abstracting, making trade offs, decomposing, visualizing and sketching. In the post-test making trade-offs was displaced by modeling as one of the most common answers. Fewer students selected visualizing as one of the least important design tasks. Abstracting saw a large increase in the number of students regarding it as one of the least important activities, while decomposing and sketching saw smaller increases.

Explaining why they selected abstracting as one of the least important design tasks, a student expressed that, “the solutions we require are very practical and do not involve a lot of abstract thinking”. While being a very popular response, no students provided a reason for selecting decomposing as least important. This may indicate that students do not have a good definition for the term as part of the design process. Three students explained that modeling was among the least effective as it was not the most effective use of time and that “you are better off prototyping and iterating”.

Table 4 presents the 2015 program results<sup>1</sup>. As in the 2016 program, abstracting saw a large increase in the number of students selecting it as one of the least important design activities. Across years, making trade-offs was less commonly selected on the post-test. Participants in both years of the program commonly selected abstracting, decomposing, and sketching as least important.



In both 2015 and 2016, while there was some movement in the rank ordering between pre-test and post-test, students preferences remained relatively consistent overall as measured before and after the design-based wilderness education program. While students orientation towards design tasks remained relatively consistent, an examination of the percentage change of individual items between the pre-test and post-test results will allow us to examine the broader trends across items that may have occurred.

Table 5 displays the design activities that had the largest absolute percent change between the pre-test and post-test in 2015 and 2016. Across both years building and making decisions are two of the actions with the greatest percentage increase of students identifying them as most important. These design activities appear to be related to immediate action. One student described building as being important because “having a good idea is nothing unless you can implement it.”

**Table 5 Largest percent change between pre- and post- test of activities identified as MOST important**

2015 percent change for MOST important design activities			2016 percent change for MOST important design activities	
Statement	% Change		Statement	% Change
Understanding the Problem	-29%*		Brainstorming	-32%**
Iterating	-18%*		Understanding the Problem	-28%*
Prototyping	-18%		Planning	-12%
Brainstorming	-14%		Prototyping	-8%
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Making Decisions	11%		Building	16%
Planning	18%		Communicating	16%
Building	21%		Making Decisions	20%

( \*\* p < 0.01 | \* p < 0.05 | Fischer's exact test)

**Table 6 Largest percent change between pre- and post- test of activities identified as LEAST important**

2015 percent change for LEAST important design activities			2016 percent change for LEAST important design activities	
Statement	% Students		Statement	% Change
Building	-14%		Making trade-offs	-44%**
Iterating	-14%		Building	-20%
Sketching	-11%		Goal Setting	-20%*
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Brainstorming	14%		Decomposing	12%
Synthesizing	18%		Abstracting	20%*
Abstracting	18%		Brainstorming	24%*

( \*\* p < .01 | \* p < .05 | Fischer's exact test)

Table 6 displays the design activities identified as least important that had the largest absolute percentage change between the pre-test and the post-test in 2015 and 2016. Across both years fewer students identified building as least important, mirroring the increased number of students that identified it as most important. Conversely, brainstorming saw significantly more students identifying it as least important, mirroring fewer students identifying it as most important, as we previously noted. Abstracting was also identified as least important more commonly across both years.

## **Discussion**

Between the pre- and post-assessment in 2016, a statistically significant number of students stopped identifying “understanding the problem” as one of the most important design-tasks. This is despite an attempt to modify the curriculum to prevent this learning outcome. The change in curriculum focused on discussion during lecture-style classroom encounters. Explicitly discussing the importance of understating the problem, and spending additional time at the beginning of the class exploring relevant scientific phenomena and establishing desired functional requirements did not contribute to students continuing to prioritize the importance of understanding the problem.

The second 2015 finding that curricular changes were meant to address was that of students placing a significantly decreased emphasis on iterating. This was somewhat successful with a 4% increase in students identifying iterating as most important in 2016, compared to an 18% decrease in 2015. However, iterating still was not one of the most common responses. Having students spending more time actively iterating during the course, especially during the expedition appeared to maintain students perspective of the importance of iteration.

While students may have continued to value iteration, prototyping saw a decreased number of students identifying it as most important after the program (-8%). While these two results may appear to be inconsistent with each other a likely explanation is the nature of the stove project. Initial “prototypes” of the stove use the same materials and fabrication techniques as a final product. Rather than viewing successive stoves as prototypes testing out ideas that lead to a final model, students may view initial prototypes simply as failed attempts at building a final product. After each failed attempt, they would modify their approach and attempt another final product, iterating through product versions while at the same time not considering themselves engaged in prototyping. Allowing for stoves to be built during the expedition would increase the opportunities available to iterate – but would not change students perspective on what it was they were iterating, a prototype or yet another “final product”.

A possible side effect of iterating being more commonly identified as important is that while planning previously saw an 18% increase being identified as most important, in 2016 it saw a 12% decrease. One student portrayed planning as being in direct opposition to iterating, indicating that it was easier to “just jump right in and try things out instead of planning things out when you’re not really sure what to do.” Presumably after trying things out, students with the opportunity to iterate would be able to go back and adjust their attempts based on the results of their attempts.

## Conclusions

In 2016, more time was spent discussing the importance of understanding the problem, yet students still stopped identifying it as important. However, there was a small, but not significant, increase in the number of students who identified iterating as one of the most important design tasks after being provided increased opportunity to practice iterating.

When students were provided with more opportunities to iterate we observed that students continued to identify it as one of the most important design tasks. This brings us to an intuitive conclusion, that actions speak louder than words. This adage may be particularly important to keep in mind when developing experiential design-based curricula. In this case, we observed that students spending time performing a specific design task (iterating) was associated with students later emphasizing its importance. On the other hand, spending more time just discussing a specific design task in a lecture format (understanding the problem) was not associated with students continuing to emphasize its importance.

When developing curriculum around a task as complex as the engineering design process it is difficult to ensure that desired learning outcomes emerge from the experience. A lesson learned is that student perception of activities may contribute greatly to the learning outcomes. If students perceive themselves as repeatedly trying to build a final product, they may not recognize that they are engaged in an iterative prototyping process.

Future work should explore the relationship between experiential hands-on curricula and design-based learning outcomes. In this case it seems that a hands on design task results in students valuing action-orientated stages of the design process. Are student learning outcomes directly related to the amount of time engaged in individual design tasks? How does the time allocated to different stages of the design process influence student learning outcomes? If we change the structure of the problem presented to students will the learning outcomes change in parallel? As design based learning curricula become increasingly popular it is necessary to further investigate how the structure of the problem and classroom environment influences learning outcomes.

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