Why to make (almost) anything:
A human-centered learning approach

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INTRODUCTION
Although CNC (Computer Numerically Controlled) machines have been in use since the late 1950s, digital fabrication laboratories and maker spaces have only recently been installed in educational institutions and community spaces. These CNC machines were originally described by their MIT creators as the “perfect slaves” [1], because, their creators thought, they would free makers from much of the manual drudgery required in constructing designs. Nowadays, once students are trained in the technical skills necessary to use these digital tools, they are expected to begin creating immediately. However, many students find it difficult to move beyond executing such simple technical tasks as laser cutting a key chain or 3D printing it. Whether in a design studio or an engineering class, teaching methods have not yet successfully addressed the integration of digital fabrication machines into the curriculum. Moreover, instructors tend to focus on the finished product rather than on the process of making it.

In this paper, we argue that the focus on teaching technical skills in maker spaces leaves students under-prepared to design and create on their own. To help remedy this problem, we introduce a human-centric learning process in which the instructor guides students in learning-to-make and making-to-learn. We define making here as a process that unites the mental action of designing with the physical action of construction.

A. MAKING IN ACADEMIA
Following the creation of the first Fabrication Lab at MIT by Neil Gershenfeld, many makerspaces and fabrication laboratories have been integrated into academic and community spaces. An ideal Fab Lab is a place where a person can make almost anything; it includes CNC machines, hand tools, and electronics benches. Today Gershenfeld’s MIT course, “How to make (almost) anything,” is being replicated in different departments within MIT and beyond. The class focuses on learning the technical skills required to use a new machine for each assignment in order to make a “thing.” The course does not address the design or creativity aspect of this process, but rather focuses on the technical skills required. Other universities have followed MIT in developing Fab Labs (or what some call “Makerspaces”) on their campuses, including the Design School in Stanford University, The School of Engineering in New York University, and The Swiss Federal Institute of Technology in Zurich. However, there has not been any research on finding an effective method for teaching students how to improvise and create on their own using tools in these makerspaces.

B. LEARNING THROUGH MAKING
In a recent paper, the first author introduced a human-machine interaction process in making and learning called I³ for its three layered operations of Imitation, Iteration and Improvisation [2] (Fig. 1). This process is based on the constructivist learning approach of learning by doing [3]. It is inspired by how we learn a craft, and how imitation -- or what the first author call here “mindful copying” -- is important for learning making skills. In the first phase, Imitation, the instructor guides the student to make something that has already been built. What the student builds does not have to be an exact copy of what s/he sees, but it should involve building following the same concept, or building part of the “thing.” Instead of spending time designing and constructing something from scratch, the student can go straight to the hands-on interaction required in making. This activity of making something that already exists helps the student to focus on acquiring the necessary technical skills to use CAD/CAM software and operate digital fabrication machines and tools. The student also starts to learn about material behavior and properties, and how all the elements come together. In the second phase, Iteration, the instructor guides the students in producing several iterations of the project, but restricts the student to making only one change per iteration. These iterations are guided by certain constraints, such as the instruction to change only the material or change the scale of the object in-the-making. For example, the student might change the geometry or material of one element, which might entail also changing whatever depends on that element. In the third phase, Improvisation, the student uses the technical, design, and making skills gained in the first two phases to improvise and create something new on his or her own.

C. THE ROLE OF THE INSTRUCTOR
While there has been great deal of focus on how fabrication machines can empower students to be creative, there has not been enough emphasis on the role of the instructor in this empowerment. Much of the problem lies with the method of instruction. Instructors tend to focus on the finished product rather than on the process of making it.

Skilful makers have acquired both the design skills and the experience to bring their creations to life. They think about materiality, about how things come together, and understand
which tools or machines will be used to produce the parts of
the artifact and how to bring them together. They know the
capabilities and limitations of each machine, and how to
tweak them to serve their purposes. Instructors of future
makers thus need to focus not only on the product itself, but
on the process of making it. They must address both issues of
how to design and ways to use these new machines to realize
designs. Beyond providing instructions on the technical
aspects of these machines, instructors need to guide the stu-
dents through what the technologies can do and when and
where they can be best employed.

In addition to guiding students during each phase, the in-
structor should give relevant mini-lectures and invite speak-
ers to talk about their making process in their projects. The
instructor should ask students to present their work at each
session and moderate the conversations that these presenta-
tions give rise to. The aim is to increase the students’ abilities
to judge and criticize work, and to learn from each other.

## D. CREATIVE MAKING

In Spring 2015, in consultation with Professor Terry Knight,
the first author used I as the curriculum structure in an MIT
course called *Computational Making: Light and Motion*. In
this course, students built interactive lighting units that
changed or moved in reaction to their surroundings. Al-
though the course was not primarily a digital fabrication
course, it relied heavily on learning and using digital fabri-
cation machines. The course consisted of twelve weekly
sessions and several recitations. Students came from different
departments, including graduate and undergraduate students
in architecture, computer science, civil engineering and me-
chanical engineering. At each session, we gave students an
assignment for the following week. Because reflection on the
action of design and making is important for learning [4],
students were required to document their making process and
use visual rules to describe the changes they had made (Fig.
6& 7). We then asked students to present their designs to the
class. Observations the first author have made outside the
academic world in community Fab Labs and “Maker Faires”
have shown the importance of the community itself in helping
makers to develop their skills. When students present in front
of their colleagues, they begin a conversation that leads to
feedback and suggestions (Fig. 1). In our classes, we ob-
served these conversations, moderated them, and eventually
provided our own feedback. We also asked students to read
relevant materials, including Lisa Iwamoto’s book *Digital
Fabrications: Architectural and Material Techniques* [5],
from which we asked students to choose some digital fabri-
cation techniques they were not already familiar with and
analyze them.

In this paper we present the students’ progress during
the course, but also focus on the importance of the role of the
instructor. We began the course by giving the students a small
exercise in describing a making process. We asked the stu-
dents to introduce new ways to make an origami piece. Some
students changed the opacity of the paper to show folded
layers, some used visual illustrations of hand motions and
folds, and others integrated verbal and visual information
directly onto the paper to be folded. This exercise became
more helpful when we later gave them the *Imitation* assign-
ment. For this assignment, we asked students to choose five
lighting units they liked from anywhere, and then select one
unit to analyze and build. We had already given them tech-
nical workshops on operating the digital fabrication machines
and software. However, the idea here was to direct them to-
ward focusing on gaining design thinking and technical skills
through building a lighting unit without having to worry
about how to start a design from scratch. As they started
building, they began to focus on the details, materials, struc-
ture, and considered which machines to use and how the
elements would come together. Students brought their light-
ing units to class, and we had a discussion on their making
processes and what could be done to improve their units (Fig.
2).

![Imitation, Iteration, and Improvisation](image)

Fig. 1, I is a multilayered operation of Imitation, Iteration and
Improvisation. Improvisation includes both Iteration and Imi-
itation, and Iteration includes Imitation.
In the next four weeks we had students do four guided Iterations. (Fig. 3 & 5) In the first Iteration, we asked students to change any one element other than material in the lighting unit they had made. This element could be geometry, structure or even scale. In the second Iteration, we asked them to change the material of one element and whatever depended on that change. In the third Iteration, we asked them to change the lighting source and pattern. The idea here was to direct them toward thinking about the intangible such as light and motion as well as the physical thing. In the fourth Iteration, we asked the students to add motion to their lighting unit. This motion could involve a physical change or a change in the light pattern, using electronics and sensors. The students used microcontrollers (primarily Arduinos) and distance and sound sensors (Fig. 4). In the Improvisation phase, we gave students the option of developing their units as a product line or making entirely new lighting units. At this point, students were able to use the tools and machines to produce new functional units without direction (Fig. 8 & 9). When it came to using electronics and programming for interaction, they were able to build on their skills and try to enhance their codes, even though some of them did not have any prior programming experience. In the full paper, we will explain the progress of two students as they progressed through the three phases of Imitation, Iteration and Improvisation.

E. DISCUSSION
Making activities for learning are embodied. They depend heavily on the direct interaction between the maker, the object-in-the-making, and the tools that are used. In this course, we wanted to introduce a new process to help bridge the gap between the machine and the novice maker. Such teaching methods are needed in order to help novice makers cope with new technologies and tools. The process we introduced enhances the learners’ sensory experiences with making and encourages them to overcome their fears of interacting with digital machines.

Fig. 2. Students present their work to the instructors and their colleagues to receive feedback. In the above photo, Jacquelyn Liu presents her early Improvisation stage of her lighting unit.

Fig. 3. Students present their work in every session. In the above photo, June Kim presents her early Iteration of lighting unit.

Fig. 4. June Kim’s Imitation and Iteration stages.

Fig. 5. June Kim’s fourth Iteration. The unit changes in color as people move around it.

Fig. 6. Estelle Yoon’s Imitation and Iteration stages.
Fig. 7, Estelle Yoon’s visual rules for assembling her lighting unit.

Fig. 8, Estelle Yoon’s making process for assembling one of her lighting unit.

Fig. 9, Estelle Yoon’s Final lighting unit in the Improvisation stage.

Fig. 10, June Kim’s Final lighting unit in the Improvisation stage.

The question before us now is how we can gauge the effectiveness of this process. How can we know whether students can really improvise and create on their own after the course ends? In an attempt to answer these questions, we gave the students questionnaires to answer before and after they had taken course. We asked the students to rate their skills in using manual tools, operating several digital fabrication machines, and programming. We also included a small design and making problem and asked them how to solve it. For example, we asked them how to build a cylinder with certain dimensions without printing it in 3D. We also asked students to do open-ended tasks such as defining the concept of improvisation, criticizing their own projects, and questioning themselves as to how they might improve those projects.

By comparing the questionnaires from before and after the course, we learned that all students felt positively about their learning experience. First, they felt much more confident in their technical skills. When asked to rate their digital fabrication knowledge after taking the class, 90% of the students rated their skills as “very good.” Some architecture students rated their programming skills in Arduino from none before the course to above average after the course. Students were also able to provide a description for several making processes for a simple making problem. When we asked them the question, “If you were given a new project to design and build, what would you do?”, they described a process similar to the one they had gone through in the class. We saw that not only were they able to transfer their technical skills to other projects in other classes, but that they had emerged from the course with a making process they could apply in the future.

As course instructors, we consider the students’ success in the non-guided Improvisation phase as a good indicator that they were now able to utilize the machines to make on their own. In our paper, we discuss our results more thoroughly and present future steps to develop and improve the I3 process.

REFERENCES