Computation in Early Design Education as Investment in Attitudes

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While education programs are generally defined in terms of learning outcomes known as knowledge, skills and attitudes, it is not always obvious how attitudes are to be gained. This study focuses on the formation of attitudes of accountability and sharing of knowledge in computational approaches to basic design education. We posit that computational thinking, even without computers, is supportive of both the reflective practice and the learning of such values in design education. We report on comparatively observed collaborative design processes of first year architecture students who externalized their thought processes through visual rules. While a reflection-in-action stage helps in learning the know-how, a second reflection on reflection-in-action deepens the understanding and initiates habits for how to think and act within and beyond the design domain, leading to attitude formation.

Keywords: design computation, attitudes, visual rules, learning outcomes, foundation design studios

INTRODUCTION: COMPUTATION AND MORAL COMPETENCES
Knowledge, skills and attitudes are often presented as a triad of competences within the context of learning outcomes in higher education (Adams 2004). Learning outcomes, for individual modules of education such as a course or a program constitute statements of what a learner is expected to know, understand and be able to demonstrate as competences at the end of a period of learning. For instance, learning outcomes for a first year design studio are defined in terms of the basic design skills and knowledge that the student is expected to acquire. Recently, computational design skills, mostly the idea of externalizing processes with (ideally visual) rules, but also the use of digital tools, have slowly come to be acknowledged in beginning architectural design studios.

By definition, learning outcomes are a composite of knowledge, skills and attitudes that an individual will attain as consequence to his or her successful engagement in a particular set of higher education experiences (Adams 2006). Nevertheless, while most institutions seek to articulate the learning outcomes in terms of acquired knowledge and developed skills, they do not explicate how attitudes are expected to be gained perhaps due to the difficulty in assessing attitudes in short term education cycles.

Attitudes are notoriously indistinct in computational design education. Often deemed a technology, computational design is usually associated with skills and abstract knowledge that absolves the student of the social responsibilities of design thinking.
We posit that computation enables the designer to externalize the process in service of a social point of interest and thus instill desired attitudes, i.e. moral competences such as sharing knowledge and accountability.

Studies that demonstrate how attitudes are conveyed to learners in higher education is scarce. Skills generally refer to the learned capacity to do something. Instead, attitudinal or affective outcomes usually involve the change or development of particular values such as empathy, ethical behaviour or respect for others (Ewell 2001). Such values, noted as "the hidden curriculum" (Dutton 1991) of a learning setting, may arise not only from the social context but the curriculum as well. In this respect, Adams (2006) suggests that learning outcomes should not be considered as statements only. Instead, they represent a particular methodological approach for curriculum design.

As such, being able to perform a certain set of domain-related skills is not enough, unless the student acquires a general habit of making use of those skills inside and outside the domain (Resnick 1999) and with a broader picture in mind. Attitudes are generally defined as a collection of habits that drive personal behaviors as well as one's patterns of thinking. In this paper, the scope is limited by accountability and collective practices that we propose as direct results of computational thinking in design education.

**Visual Rules in Foundation Design Studio: Reflection in and on Action**

In foundation design studios, the student is usually engaged with various abstract tasks to define relations between forms as the given formal vocabulary facilitates the reasoning process. Commonly there is interest in utilising tools such as comparative display, conversation, and systematic visual representations, to support the externalisation of the reasoning. These approaches encourage the students to reflect on their own reasoning in the decision-making context. Duly, Meijers et al. (2005) has suggested that design thinking should be included as a fundamental competence to be acquired in higher education. Even if this suggestion is not commonly followed through, Buchanan (2008) has been advocating the teaching of design attitudes such as responsibility for good organisation and decision-making in disciplines other than design.

Similarly but within the context of the design studio, we suggest that the knowledge and skills acquired while dealing with form in design education may extend to attitudes and organisational ability. Stiny (1980) points out that visual thinking is instrumental in understanding the spatial relations that constitute designs. While rule-based design methods are generally associated with parametric design, rule-based approaches can support visual and perceptual properties of shapes. There have been proposals in integrating such approaches to design education in general (Knight 1999) yet there is not much research done on the attitudes supported by such pedagogical approaches.

We aim to show that computational design thinking supports the learning of positive values in design education. The hypothesis is merely based on the fact that it enables an externalisation of design thinking, sharing, and hence accountability. Our motivation is to provide yet another reason for introducing computing early on in design education among with other fundamental skills and knowledge. Trying to grasp the relational system underlying a design through visual rules helps in developing reasoning, choices, and judgement. A designer’s shape rules are not only tools to control the relations between shapes but they also facilitate the reasoning process towards an increased understanding and the improvement of personal attitudes.

**A Design Experiment in a Foundation Design Studio**

Our study involves comparatively observing collaborative design processes in volunteering first year undergraduate architecture students, over the course of a month in various types of group projects. In the
In this study, students were encouraged to externalize their thought processes through rules for reflection. While a first stage of reflection helps in learning the know-how or design skills, namely reflection in action, a second stage of reflection is necessary for developing habits of the mind and of knowing how to think and act: reflection on reflection in action. In two tier tasks, students first completed a design assignment, then they were introduced to notions of visual rules while assessment. Students were then asked to interpret others’ work through visual rules and apply them.

This protocol was repeated in a sequence of assignments so that students might develop regular opportunities to critically evaluate themselves and their peers. The assignments progress by adding a new variable in each stage. Towards the end of the process, they were expected to reflect on the collective and individual process comparatively, in terms of what rules they used and how changed their own rules on the way. This demonstrated that rule-based approaches to design help not only in dealing with form relations, but they become instrumental for the external interpretation of actions. When treated as a whole, rule-based approaches help in developing strategies of knowing how to act and think within and beyond the design domain, leading to attitude formation.

The design experiment was conducted with fifteen volunteering first year undergraduate architecture students at Epoka University in Albania. Students had been exposed, for at least one term, to the basics of design. The design tasks were structured on two-dimensional formal organizations achieved through a cut-and-paste technique of various shapes within a given boundary. As part of the design knowledge conveyed in the foundational design studio, students were asked to achieve unified wholes by paying attention to the relationships established between primitive elements and at the same time to preserve the identity of those elements. Overlaps of elements were allowed. Moreover, students were encouraged to consider the shapes emerging from the overlapping and the background as a design input while defining relationships in different orders.

The sequence of the assignments was as follows:

1. Folding a blank sheet of paper in five consecutive steps.
2. Unfolding the paper, emphasizing the folding lines and extracting emerging shapes.
3. Making a two-dimensional composition with seven of the elements derived from Stage 2; each repeated three times. Overlapping is allowed; materials are black and grey on white paper (35x50 cm). Students are introduced to visual rules while collective assessment, by identifying possible rules within existing compositions.
4. Making a two-dimensional composition with three of the elements used in Stage 3; each repeated seven times. Overlapping is allowed, materials are black and grey on white paper (35x50 cm). Then, exchanging the design work with the fellow student. Identifying with visual rules, possible repeated patterns and relations present in the design organization. (Student 1 on Student 2 and Student 2 on Student 1)
5. Re-making a two-dimensional composition with three elements used by the fellow student, each repeated seven times. Students are asked to follow and apply the identified rules in the design of their peer. Scaling and overlapping is allowed; materials are black and grey on white paper (35x50 cm). Exchanging again the design work with the previous fellow student. Identifying with visual rules, possible repeated patterns and relations present in the design organization: Student 1 on (Student 2 on Student 1) and Student 2 on (Student 1 on Student 2)
6. Making a two-dimensional composition with the three elements used in Stage 4, by following the rules identified in Stage 5. Apart from scaling and overlapping, one of the elements is assigned a red color, while the rest is black and grey on white paper (35x50 cm).
In the normal run of a foundational design course, assignments are of short duration and proceed in a fast pace by adding a variable each time. In this proposal, we followed a slower process that also moved back and forth. Students were asked to interpret shape relations with visual rules, and to re-make the assignments by reflecting on rules. The aim of interpreting the design works with rules is to show students that rules are good tools to formalize their design thinking process and to freeze in time the possible decisions taken. Such an interpretation helps students exchange their ideas and learn from one another, even without the presence of an authoritative figure, such as an instructor. In the long run, this may support students to become self-critical. The problem with rules stands in their abundance. Students had difficulties in deciding on which rules to identify and apply. Generally students were encouraged to identify rules standing for the general layout organization of the canvas (35x50 cm), part-to-part and part-to-whole relationships.

**The Process: Reflection-in-Action and Reflection on Reflection-in-Action**

The series of the design assignments started with a paper folding exercise (Figure 1). Each student was given a blank sheet of paper in A4 format. Without using any drawing or measurement equipment, students were asked to fold the paper in five consecutive steps. The haptic feedback is not taken into account. Paper folding served as a starting point to introduce students to the notions of shape embedding as they start with a whole in their hands. Students proceeded by folding what emerged from the previous step in a repetitive fashion. While the guiding principle of "the whole gets divided into its parts" was the same for all of the students, the outcomes were varying.

Students were asked to make a unified whole with seven shapes extracted from the folded paper pattern and to repeat each shape three times. The sub-shapes vary for each student. The key is in the making use of the relational system present in each folding pattern. Below are illustrations for some of the students' works corresponding to this step. Students were not yet introduced to how visual rules work within a design organisation. Although there were some attempts to consider the background and the overlapping as design input by Student S1 and Student S3, as illustrated in Figure 2., the organisations generally lacked order (Figure 2, Student S4) and non-repetitive shape-relations were prevailing (Student S2).

At the end of Stage 3, students were introduced to the notion of visual rules in support of the panel discussions that usually take place for assessment. They were encouraged to view and represent their own process through formal devices such as rules. Viewing the whole process as computable, makes the students be in control of their design decisions. This is also possible due to the nature of two-dimensional design works taking place in foundation design studios, where compositions are achieved through geometric transformations of primitive shapes and setting relations between the different transformations. Keeping in mind the potentials of visual rules, students were asked to re-make the assignment of Stage
Figure 2
Student works of Stage 3, before being exposed to visual rules. (left to right: Student S1, Student S2, Student S3, Student S4).

Figure 3
Design works of the same students, done in Stage 4, after being exposed to visual rules.

Figure 4
The interpretation of the Student S3 work done in Stage 4, with a small change of the design as it could have ended, referring to the followed rules. A shape rule relating the extracted sub-shapes of Stage 2.

3, as prescribed in Stage 4. The works of the same previous students are illustrated in Figure 3, after being introduced to visual rules. There is a clear improvement from Stage 3 to Stage 4, in terms of the spatial relations defined. This view is relevant for more than half of the group participating in the workshop.

The comparison between the two groups of illustrations points towards more responsible acts taken by the students from Stage 3 to Stage 4, as a result of making use of visual rules in their personal design processes. Below follows an interpretation with rules of the design process of Student S3 in Figure 3, done retrospectively. Ignoring the different weights assigned to the shapes in composition, the student work is redrawn as shown in Figure 4 and Figure 5.

The following stages of the study were set in support of the argument that rules help the externalisation of the design thinking process, hence sharing and accountability. The development of such attitudes necessitates the inclusion of collaborative learning similar to role playing. The design process was reversed at this point. Students were first asked
to identify some rules standing for the visually repeating patterns and relations, within the compositions done in Stage 4 by their fellow student. While this reflection stage helps in learning the know-how of design, namely reflection in action, a second reflection stage we think is necessary to deepen understanding and developing habits of knowing how to think and act: reflection on reflection in action. After identifying the visual rules, students, by working in pairs, were asked to follow and apply the rules again in a new organisation. This process was repeated twice.

Making students see their design works as visual computations helps them not only observe and interpret but also share their design decisions. In turn, students become competent in critically judging different design decisions rather than following them blindly. In Figure 6, additional to interpreting the composition with rules, Student S6 does not hesitate to comment on possible "deficiencies" in the design of her fellow Student S5. Starting with the organisation of the layout, parts are arranged in alignment with each other as shown in Figure 7. Student S6 acknowledges this spatial relation in her Rule 2 and reapply it in her work by fitting the overall design within the boundaries. As a result, in the second interpretation, the student handles the figure-ground relationship along the boundary better compared to the first.

Furthermore, Rule 3 and Rule 4 point to shape relations standing for the overlapping between two shapes and the emergence of the background as another shape. Student S6 wrote: "Something very positive in Student S5 work is that the overlapping part is one of the main shapes itself. But the problem is that she is not consistent in the repetition of Rule 3." Student S6 commented on another rule as well: "I have noticed that there is an approach where the background participates itself to form shapes that already exist. But this approach was lost in many other cases. Sometimes some strip lines are formed and the eyes get lost and confused while reading the shapes."

Figure 5
The possible visual process to obtain Student S3 work:
(left to right, top row) A shape rule showing the repetition of the unit; the same rule applied recursively;
(left to right, bottom row) New shapes are perceived at another level, as a result of the alignment of the shape boundaries. The new element translates on the horizontal axis and reflects according to the hypotenuse; Shape rule where the canvas height becomes a determinant; a shape rule for assigning different tones to the parts, by relating contrastively the figure and the ground.
Figure 6
Interpretation of Student S5 design by her fellow Student S6, through visual rules. Student S6 rules point to shape transformation (Rule 1), general layout (Rule 2), shape relations and emergence of new shapes from the overlapping and the background (Rule 3 and Rule 4).
These statements show once more the potentials of including visual rules in the studio discussions. Student S6 not only interpreted design actions with references to visual rules, but was also able to produce arguments for why some relations were good and why some were not. Although there is room for improvement, there is a clear evidence that the interpretation of the second student on the first is more consistent with the original intentions. We report that ten out of fifteen students developed more aware and consistent interpretations for the work of their fellow students. The students not only interpreted what they saw, but also reflected on the other students' reflections while both extracting rules and reapplying them.

**DISCUSSION AND CONCLUDING REMARKS**

This study turns a spotlight on attitudes that ideally complement the acquired knowledge and skills, but are often left tacit. Contrary to the general view of seeing attitude formation as a relevant competence for master graduates, the aim here is to make attitudes part of the learning process at the very beginning, along with the gaining of basic knowledge and skills. Our focus is on the formation of attitudes that directly relate to the sharing of knowledge and the accountability of the design decisions.

Accountability is defined as the responsibility for performance, or the obligation to report to others, to explain, to justify the taken actions (Huisman and Currie 2004). Our basic premise is that making students see their designs as visual-spatial computations helps the students observe what they are doing, how they are doing and more importantly, that they reach an understanding of why they are doing things...
the way they do. Moreover, rules that capture the visual stages of a transformation externalise knowledge to be shared and to be questioned at various instances of design and production. Previous studies have acknowledged the role of formal tools like visual rules in externalising the design thinking process in support of the "reflective practice".

Our study included observing fifteen first year architecture students with the aim of assessing attitudes. The students used visual rules as a tool to reflect upon their personal and their fellow students' design processes while defining or identifying different shape relations. We acknowledge that their processes would have been better studied over a longer period of time and in future studies, more systematic methods should be tried for assessing attitudes. All of the students were able to define rules and relate parts at one level though some of them did not succeed to form unified wholes as shown in Figure 8, regarding the work of Student S2 on Student S1. The Student S2 himself is reported saying that he felt trapped while reapplying the rules as if he was doing the same composition again. This might be related with the abundance of rules identified in a composition and their specifications.

Nevertheless, by working in pairs, students tried to be accountable to one another. For instance, one of the students claimed in the post-experiment discussion that "although we were working on each other's design works, I felt the whole process very personalised. Now I may easily recognise my fellow student's work amid many others." This means that in interaction with each other, students start to understand their personal differences as well as others' design reasoning process. By visualising their steps as an articulation of reflection, students learn to share their learning with others and understand whether they are doing things differently or similarly. This may be developed further towards the role of rules in developing personal styles and multiplicity in design as shown briefly in the paper folding exercise in Figure 1.

This research is part of an ongoing study on the role of attitudes in student learning in higher education. In this study we showed how students might learn to be accountable to others by way of a computational approach to the foundation design studio course. The general objective is to make students learn to practice attitudes in other settings as well. Previous studies have acknowledged the difficulty of assessing attitudes as they are a time-dependent competency. A further development of this study might be an integration of visual rules as part of a studio pedagogy for the whole academic year and to observe the habits of thinking and acting that students may develop over longer periods of their education.

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