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Creative engineers: Is abductive reasoning encouraged enough in degree project work?

Ciarán J. O'Reilly[a,*]

[a] *KTH Royal Institute of Technology, Centre for ECO^2 Vehicle Design, Teknikringen 8, SE-100 44 Stockholm, Sweden*

* Corresponding author. Tel.: +46-8-790-8085. *E-mail address:* ciaran@kth.se

Abstract

Creativity is considered to be an important ability for an engineer to have, and it is therefore important that the development of this ability is structured into the education of engineering students, along with the ability to apply, analyse and evaluate based on existent knowledge. In this paper, the importance of abduction in creative engineering processes is briefly reviewed. It has been shown that abductive reasoning plays a key role in design as it is the only logical operation that introduces new ideas. Its encouragement within the KTH Royal Institute of Technology's degree projects at the Department of Aeronautical and Vehicle Engineering is analysed by examining the stated intended learning outcomes, and through interviewing students. It is found that abductive reasoning is not explicitly encouraged within the intended learning outcomes of these degree project courses, despite its importance in creative thinking. Although, it is very likely that at least some abduction takes place in the project work, its absence from the intended learning outcomes means that students may not have a felt need to demonstrate their abductive reasoning, and supervisors may encourage only non-creative deductive or inductive reasoning. A more explicit inclusion of abductive reasoning in the intended learning outcomes would help both students and supervisors to include creative thinking in the degree project courses.

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1. Introduction

Creativity has always been closely associated with engineering. The term itself is derived from the Latin ingenium meaning "cleverness" and ingeniare meaning "to create, contrive or devise", and it shares its roots with ingenuity. For a technical university such as KTH Royal Institute of Technology it is therefore important that the ability to create and innovate is structured into the education of engineering students, along with ability to apply, analyse and evaluate based on existent knowledge. This is reflected in the KTH Vision 2027 for Education [1], which states that:

> "KTH education stimulates independent thinking, *creativity* and curiosity and applies critical examination of existing technological practices. Engineers and architects identify solutions which embody both *innovation* and *enhancement* with a clear social dimension, a distinct focus on sustainability and, for some, also an artistic dimension."

and:

> "KTH nurtures a culture characterised by solid knowledge in basic engineering areas, *creativity*, communication and *ingenuity* – valuable properties in modern international settings."

An obvious challenge for teachers and supervisors at KTH is to understand where and how creative abilities can be facilitated and encouraged in the student's learning.

Where can creativity be encouraged is perhaps the easier part. Two areas where creativity is of value are in the creation of solutions (design) and in the generation of theories (science) – in other words, to create solutions to problems and to generate knowledge about a problem. In both cases, the generated designs or knowledge must be subsequently tested and verified. A natural place to set these types of activities in the engineering programmes is within project work, specifically degree project work.

How can creativity be encouraged within project work is a greater challenge. A good starting point would be to structure it into the work through the Course Plan. Like all courses at KTH, degree project courses are defined within their Course Plans, which sets out the intended learning outcomes (ILOs), activities and assessment criteria. The Course Plan could therefore be interpreted as encouraging certain activities, at least in the sense that they set out what must be done. Students can of course always go beyond this level, but they are not explicitly encouraged to do so. As supervisors should facilitate the students' achievement of the ILOs, it is maybe questionable how strongly learning outcomes beyond the ILOs can be pushed. The most robust approach would be to include creative aspects in the ILOs.

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Two sub-questions that derive from this are:

1. Is creativity, either implicitly or explicitly, included in the intended learning outcomes, and if so
2. What activities and assessment criteria ought to apply?

Before addressing these questions, it is necessary to develop what encouraging creative thinking means here.

Creativity can be defined as the ability to transcend traditional ideas, rules, patterns, relationships, or the like, and to create meaningful new ideas, forms, methods, interpretations, etc. [2]. The creative process is often necessitated by the need to solve problems, and at its core is the generation of new ideas or divergent thinking.

One approach for promoting creativity in engineers is to encourage "intuition", or the ability to understand something instinctively, without the need for conscious reasoning. Aside from implementation difficulties, this in its pure form may effectively amount to encouraging guessing or a trial-and-error strategy, which for solving large complex open problems is unlikely to result in a solution.

A more rigorous approach is to encourage "logical reasoning" or a type of logical creativity to influence decision-making processes. Logical reasoning may be classified into three parts – deductive, inductive and abductive reasoning [3]. Of these, abductive reasoning is the only logical operation that introduces new ideas [4]. Creativity can be seen as intrinsically related to the process of producing new ideas, habits, etc. through abduction [5]. Therefore, creativity is intended here to mean this reasoned creativity based on abductive reasoning rather than intuition.

Abductive reasoning is a form of logical inference, introduced by Charles Peirce [6], which goes from an observation to a theory that accounts for the observation. Ideally the simplest and most-likely explanation is sought. Abductive reasoning can be understood as as "hypothesis to the best design" or "inference to the best explanation". It has been shown that abductive reasoning plays a key role in design [7–9].

This paper will focus on addressing the first question posed above, which amounts to "is abductive reasoning, implicitly or explicitly, included in the degree project ILOs?" In Section 2, abduction is briefly summarised. In Section 3, the ILOs for the degree project courses at KTH's Department of Aeronautical and Vehicle Engineering are presented, and are assessed to see if they encourage abduction. This assessment is supplemented with interviews of students of these project courses that are presented in Section 4. The results of this assessment are discussed in Section 5 along with some discussion of the second question above on how abductive reasoning might look as a learning activity and assessment criteria. Conclusions are drawn in Section 6.

2. Abductive reasoning

There are three forms of logical reasoning – deductive, inductive and abductive [10]. A short explanation of each is given Table 1. All three forms are integral to problem solving. Deduction and induction consist of drawing conclusions from what is known. Abduction explains what is known or most likely. Note that deductive/inductive reasoning and abductive reasoning differ in the direction in which a rule like "a entails b" is used for inference.

Table 1. Logical reasoning.

Reasoning form	Explanation
Deduction	Deriving b from a only where b is a formal logical consequence of a. In other words, deduction derives the consequences of the assumed.
Induction	Inferring b from a, where b does not follow necessarily from a. a might give a very good reason to accept b, but it does not ensure b.
Abduction	Inferring a as an explanation of b. Abduction allows the precondition a to be abduced from the consequence b.

Design researchers generally promote abductive logic as the lifeblood of creative design [8,11–15]. In design, abductive reasoning is implicated in at least two important situations – in synthesising complex and contradictory information to generate insight, and in reasoning toward new solutions for design problems (i.e. from function to form) [11,16]. The latter form of abduction has been referred to as "innovative" abduction, with the former labelled as "explanatory" abduction [8]. Although many kinds of abduction may be classified, it is sufficient for the purposes of this paper to limit the discussion to explanatory and innovative. For a more detailed classification, the reader is referred to Ref. [17].

Abductive reasoning is not unique to design. In science, these two forms are usually referred to as "selective" (explanatory) and creative (innovative) abduction, with the latter being central to the growth of scientific knowledge given its emphasis on generating new plausible hypotheses that can be tested [18]. Simply stated, abductive reasoning introduces hypotheses and theories to explain given facts.

For both design and science, the key to using knowledge effectively is to exploit all three forms of logical reasoning. This is because it is not enough to supplement the knowledge base with parameters from previous experiences only [19]. For example, in design one form of logical reasoning may be emphasised over another at different stages in the development, such as more innovative abduction at the start and more deductive logic towards the end [11,15]. Concept selection transcends merely selecting from clearly defined options, and should not only be about the evaluation of the design concept as it is. It should also be about inferring what it could be, which requires innovative abductive reasoning. An over-emphasis on deductive reasoning could inadvertently eliminate potentially fruitful concepts as an unintended consequence.

In summary, it is therefore essential that KTH engineering students are encouraged to use all three forms of logical reasoning, but particularly abductive reasoning if creative and innovative abilities are to be developed.

3. Assessment of the degree project courses' ILOs

At KTH, the first-cycle (Bachelor's) and second-cycle (Master's) degree projects are structured courses. This means that they each have a formal Course Plan with explicit intended learning outcomes (ILOs), requirements for completion, etc. The intention is that both the activities performed within the project, and the assessment of that work, are constructively