

## ISSUES IN LEARNING ENGINEERING GRAPHICS FUNDAMENTALS: SHALL WE BLAME CAD?

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### Abstract

Several studies report that many novice engineers result to be skilled in CAD but poor in knowledge of the basics, visualization and spatial skills and ability in freehand sketching. There is a debate on if such lack of fundamentals dues or not to the increasing role of CAD and the decreasing role of manual drawing in the basic courses of engineering graphics.

This study aimed to investigate the issues related to the use of CAD and manual drawing in teaching engineering graphics fundamentals by a review of the literature of the Engineering Design Graphics Journal and the International Journal of Technology and Design Education from 2000 to date.

It was found that current students: have a lower initial level of knowledge and experience; have little chance to develop sketching and visualization skills if trained only by CAD; and their assessment usually focuses more on CAD skills than on the knowledge of the basics.

Solutions proposed to such issues are: introductory courses of manual drawing at college and high schools; assessment of students' initial skills; and tests more focused on the knowledge of the rules and basics of engineering graphics language.

**Keywords:** Design education, Design learning, Pedagogy, Engineering Drawing, Computer aided design (CAD)

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## **1 INTRODUCTION**

Several studies report that novice engineers are acknowledged to be skilled in CAD but they lack of mastery of engineering graphics fundamentals. Particularly, they seem to be poor in knowledge of basics and freehand sketching, and with lower spatial and visualization skills and attention to drawing strategies, if compared to their older colleagues.

Several researchers claim that such lack of fundamentals in novice engineers dues to the fact that basics and visual concepts are less and less taught in engineering graphics education because of the increasing time spent on teaching CAD, and the progressive disappearing of manual drawing from engineering graphics programs. On the other side, the big majority of lecturers and researchers consider manual drawing a no longer required skill for industry, and argue that CAD is to be applied during the whole process of teaching engineering graphics.

This study aimed to possess a fuller apprehension of this debate and to look into the topics connected to the use of CAD and manual drawing in teaching engineering graphics fundamentals.

To achieve that aim, we made a review of the literature about the teaching of engineering graphics to first-year engineering students. We focused the research on two journals: the Engineering Design Graphics Journal and the International Journal of Technology and Design Education. The research took papers from 2000 to date, and selected papers on trends in engineering graphics education along with perceptual experiences of students, teachers and industrials on the roles of CAD and manual drawing in education. The experiences and argumentations gathered from the review were then compared to our experience in engineering graphics education at the University of Brescia.

## **2 USING CAD AS A FIRST APPROACH TO ENGINEERING GRAPHICS**

The advent of CAD has changed the way engineering graphics is taught. CAD has become central in engineering graphics programs, and it has been dominant in didactic education in both schools and industry for the last twenty years (Barr, 2012; Chester, 2007). The use of CAD has shifted engineering graphics education from the area of mechanical engineering to the area of computer instruction (Field, 2004), with the aim to create engineers skilled in “creating solid computer models”, which is considered “the first engineering graphics educational outcome for the global engineer”, as resulted from a view on American engineering graphics faculties (Barr, 2012).

With the implementation of CAD in education, long-standing techniques of descriptive geometry and manual geometric construction appear to be seen no longer desirable outcomes in engineering graphics education (Barr, 2012), and many engineering graphics faculties have been acting to eliminate the use of manual instruments from instructional practices (Clark and Scales, 2006). CAD is hence currently used in many universities from the start of first-year engineering graphics classes.

### **2.1 Some of the advantages**

There are several advantages of using CAD as a first approach to engineering graphics for first-year engineering student. Students appear to be very attracted by the latest graphics application, probably because they are used to manage technologies like the Internet, 3D video games, mobile telephones, and other similar instruments (La Verne and Meyers, 2007). Freshmen also have a clear picture of the reasons why they should learn CAD: keeping up with the times; future career expectations and opportunities; and diversity, accuracy, efficiency and speed of production of quality output (McCardle, 2002; McLaren, 2008).

The use of CAD gives students the opportunity to approach to engineering design by means of a tool that involves the various steps of product design: CAD allows animations, analysis and testing without actually produce, virtual manufacturing and prototyping (Patil and Kumar, 2012), mathematical modelling and links with 3D graphics generation and photorealistic renderings (McCardle, 2002). Software and applications related to CAD are used in several courses of engineering education, and it is therefore important to start developing a working knowledge of the software from the beginning of the courses of engineering graphics.

During the learning process, CAD allows to design more quickly and with greater accuracy than by manual drawing (La Verne and Meyers, 2007). According to our experience, by the use of CAD, particularly 3D CAD, in introductory engineering graphics courses, students develop the ability to

visually convert the three-dimensional drawing into orthogonal projections, since students can easily manipulate the three-dimensional drawing by a click of the mouse. Making changes and correcting mistakes on CAD is easier (McLaren, 2008), as it is to preserve and transfer CAD drawings to the teachers for reviews and corrections (Patil and Kumar, 2012). CAD, once learned, is also faster to master than manual drawing, and it hence allows faculties to include more ideas and subjects in engineering graphics courses (La Verne and Meyers, 2007). CAD also facilitates the networking (McCardle, 2002) and group activities that are acknowledged to positively influence the learning of students (Delahunty et al., 2013).

## 2.2 Some of the issues

According to Brown (2009) and McLaren (2008), novice engineers trained to use only CAD they result to be skilled CAD operators, but without a deep understanding of the fundamentals of engineering graphics. Particularly, novice engineers seem to: have a poor understanding of the fundamentals of constructing a drawing; lack confidence in sketching; lack appreciation of the need to comply with rules, conventions and standards (McLaren, 2008); need improvement in visualization of the three-dimensional form of an object based on two-dimensional drawings; lack ability to interpret 2D drawings with interconnected parts (Abdullah et al., 2011); and have weak spatial intuition and reasoning (Field, 2004). The lack of such abilities appears to be significant for industries, which expect engineers to have a 'real understanding', remote from CAD (McLaren, 2008).

The review made in this study found three possible factors explaining such lack of mastery of engineering graphics fundamentals:

1. The lower level of quality of students entering engineering graphics programs: students are no longer mostly from technical high schools and they meet more difficulties in learning fundamentals (and CAD) because of their poor or none prior experience in engineering graphics;
2. The less time available to learn fundamentals and to develop spatial skills through manual drawing activities, because the training is concentrated on using CAD and the time devoted to teach the basics and manual drawing is cut;
3. The assessment of skills focused more on CAD than on the abilities in master the fundamentals, thus diverting students' attention from learning the basic principles and rules of engineering graphics.

In Figure 1, such factors are graphically represented by using a Reference Model, drawn by following the indications of Blessing and Chakrabarti (2009).

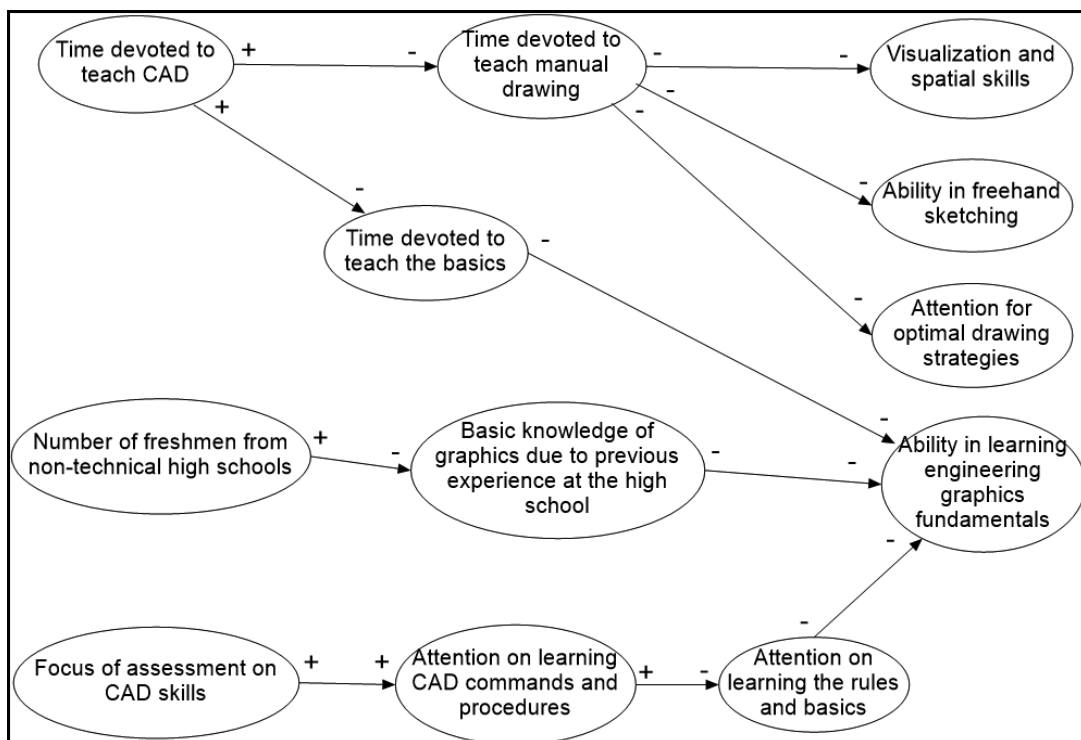


Figure 1. Reference Model based on the findings in the literature

The nodes represent aspects of the existing situation (factors) that influence other aspects of this situation. The combination of '+' and '-' signs at the ends of a link describes how the value of the attribute of the factor at one end relates to the value of the attribute of the factor at the other end. For example, in Figure 1, a higher number of freshmen from non-technical high schools (+) relates to a lower level of basic knowledge of graphics due previous experience at the high school (-). The aspects and the links shown in Figure 1 are discussed in detail in the following paragraphs.

### **3 FACTORS INFLUENCING THE LEARNING OF FUNDAMENTALS**

#### **3.1 Lower level of students entering engineering graphics programs at college**

The ability in learning engineering graphics fundamentals at university is significantly influenced by prior graphics experience and education at the high school (Delahunty et al., 2013; McCardle, 2002). Until some years ago, the largest part of first-year engineering students were from technical high schools. In technical high schools, students develop spatial reason abilities through geometry and drafting courses, and they learn the basic functions of machine elements and drawings (Field, 2004). Despite there are engineering colleges that evaluate student entry requirements in design and technology (see an example in McCardle, 2002), many universities assume that freshmen already own some knowledge of engineering graphics and no skills in graphics or engineering graphics are asked to students as prerequisites (Elrod and Stewart, 2005).

The characteristics of first-year engineering students have significantly changed in the last years. The number of students from the non-technical high school entering engineering colleges has dramatically increased. For example, at the University of Brescia, in 2013, 95 out of 117 (81.2%) of the students enrolled in the first year of a degree in industrial engineering were from non-technical high schools (56.4% from the scientific high school). It is acknowledged that students from the non-technical high school have little or none real knowledge of engineering applications (Willmot and Perkin, 2012) and they are usually both poor in engineering graphics fundamentals and illiterate in CAD. As a consequence, when facing a first course on engineering graphics taught by using CAD, they have to fill two gaps of knowledge: the knowledge related to the basics and the knowledge related to the use of the software, that students from technical high schools have generally already approached. The learning process of freshmen without a grounding in graphics and technics and the learning process of freshmen with prior graphics experience at the high school are also different:

- Students without a technical grounding need more time to understand than their colleagues from technical high schools, also to proficiently use CAD (Brown, 2009; Chester, 2007; La Verne and Meyers, 2007).
- Students without a grounding in engineering graphics generally fare worse with CAD than their colleagues (McLaren, 2008) and therefore they are likely to achieve lower learning outcomes related to CAD.
- Students without pre-collegiate graphics experience they may develop a lower level of self-efficacy and self-confidence if compared to their peers from technical high schools (Fantz et al., 2011; Metraglia et al., 2013). This is a matter of concern for educators, since self-efficacy beliefs determine the effort, persistence and resilience of students through the process of learning (Pajares, 1996), and such weaker students may need specific instruments and teaching approaches to increase their motivation (Metraglia and Villa, 2014).

In sum, the growing number of first-year engineering students with little or none pre-collegiate graphics experience need tailored instructional programs to learn the basics that their peers with a technical background already own. In introductory engineering graphics courses focused on CAD since the beginning, the students without a graphics background may have not enough time to learn the ropes of engineering graphics, and though they may fill their initial gap related to the use of the software, they may result poor in understanding of fundamentals, as argued by McLaren (2008) and Brown (2009).

#### **3.2 Lower possibility to develop skills related to manual drawing when only CAD is used**

Several studies (Clark and Scales, 2000; Contero et al., 2005; La Verne and Meyers, 2007; McCardle, 2002) agree that the time devoted to teach manual graphics has been progressively reduced by the

increasing of time devoted to teach CAD, and that visual concepts are less and less considered in engineering graphics programs. First-year students who are taught only by CAD, they may miss the opportunity to develop several skills related to the learning through manual drawing. Delahunty et al. (2013) and McLaren (2008) made a comprehensive review of such skills, which are considered very important in industry.

### **3.2.1 Spatial abilities and visualization skills**

It is acknowledged that sketching or drawing improves spatial abilities (Chester, 2007; Delahunty et al., 2013; Mohler and Miller, 2008) and those students who are exposed to hand-drawn, they acquire the ability to “see” ideas in the mind and render them into drawings (La Verne and Meyers, 2007). Sketching aids abstract concept representation and it allows students to refine their cognitive processes and to better explore new concepts (Delahunty et al., 2013). By manual technical drawing, students acquire skills in seeing and manipulating 2D and 3D drawings and the ability to transpose images in mind before that on software (McLaren, 2008).

According to La Verne and Meyers (2007) and McLaren (2008), the growth of such visualization and spatial skills is poor in courses that stress Computer Aided Design methods. Mohler and Miller (2008) argue that the use of digital tools seems to decrease the perceived need to engage in drawing and sketching, and hence the focus on spatial ability training. In fact, freshmen often have a poor consideration of the importance of hand-drawing and sketching (La Verne and Meyers, 2007), and most of them have difficulties in keeping up their attention when engineering graphics is approached by classic paper-and-pencil exercises (Contero et al., 2005).

At our University, the perception of the importance of sketching appears to be significantly different between industrial design freshmen and mechanical or industrial engineering freshmen. Industrial design students tend to prefer designing by hand, whereas mechanical and industrial engineering students prefer using CAD. We interpret this difference saying that industrial designers are probably aware that they will frequently use sketching or manual drawing in their professional career and therefore they may give more value to that kind of skill, whereas engineering students may think that in their career they will use only CAD to design. We think that such low consideration of sketching by first-year engineering students may also be affected by the fact that: 1) many of them consider the ability to draw by hand as a natural talent that people either have or they have not; 2) most of such freshmen think they are without that natural talent. Ault and John (2010) add that additional factors explaining the decline in the visualization skills of engineering students are to be found in the fact that manipulative toys and mechanical devices have been replaced by electronic toys: students have then fewer possibilities to develop spatial skills in manual activities before the university, and they have in fact poorer visualization skills than students entering engineering colleges a decade earlier.

### **3.2.2 Accuracy, knowledge of standards, a sense of control during the process of drawing**

The advantages of using manual drawing in engineering graphics education have been deeply explored by McLaren (2008). For example, manual drawing is considered right to “allow the learner to grasp the operation of CAD quicker without being encumbered by learning, concurrently, basic aspects of layout, conventions and relationships between views”. According to McLaren (2008) during the process of learning, students recognize easier low quality drawings and inaccurate results, because the flaws are publicly visible. Students are therefore motivated to look critically at the drawing and raise their attention to the understanding and to improve technique. CAD drawings are clear and look accurate, and there is no evidence that the drawing was made by applying an optimal strategy or a suboptimal strategy. By drawing manually, students are forced to develop accuracy skills and knowledge of fundamentals as layout, standards and conventions, because the feedback on the quality is evident both at the end and also during the process of drawing. In CAD drawings, problems are found only when others manipulate them and there is no evident feedback during the drafting process (McLaren, 2008).

The fact that a drawing drawn by hand is ‘personal’ seems to be really valued by pupils, who generally develop a greater sense of control and ownership and feel more affected in the process of improvement (McCardle, 2002). The survey of McLaren (2008) indicates enjoyment and satisfaction in producing manual drawing, along with a greater sense of artistry. The industrials interviewed by McLaren (2008) also consider perseverance, care for precision and the importance of planning other important values developed through manual drawing. Considering the importance of planning as an example, to correct

the planning of a drawing in CAD it takes a click of the mouse, whereas in a traditional drawing designers need to design the layout, and they therefore need to make a picture in their minds before drawing (the aforementioned visualization skills).

### **3.2.3 The pencil-and-paper approach**

Engineers trained “with a pen and pencil in hand” also seem to approach design problems differently if compared to engineers trained in computerized design technology (Brown, 2009). According to our experience, engineers trained only by CAD they tend to sketch a new concept starting with CAD, whereas engineers who started their training by manually drawing they tend to prefer pencil and paper. Despite many teachers consider the ability of using pencil and paper a “no longer desirable outcome” in engineering graphics education, as reported by Barr (2012), the ‘pencil-and-paper’ approach may help engineering designers in several ways:

- It is quicker than CAD both to record ideas and to compare them (McLaren, 2008);
- It is not tied to a specific CAD and therefore it can be applied in all of the contexts;
- The designer can reason before spending effort and time on CAD models that could look nice but that could be then put aside because of an unsatisfactory planning;
- The pencil is a ‘democratic’ shared tool of communication that can be used in teamwork with engineers, designers and technicians who may have different skills in CAD.

We believe that such ‘pencil-and-paper’ ability may also help students in other engineering courses where the graphic modelling of problems is essential to understanding and to find solutions (e.g. Physics, structural analysis, analytical mechanics).

In sum, students who are not taught engineering graphics by manual drawing they may miss the possibility to develop important skills such as accuracy, creativity, visualization and abstraction of objects from drawings, and the ability in freehand sketching. This may result in novice engineers that are weak in spatial intuition and reasoning, as argued by Field (2004), and weak in visualizing objects from drawings, as indicated by Abdullah et al. (2011). Since CAD allows students to skip a higher level of care for a correct application of the engineering graphics rules, novice engineers may also lack the perception to have to comply with conventions and standards, as argued by McLaren (2008).

### **3.3 Assessment of skills focused on CAD rather than on fundamentals**

The study of McLaren (2008) on the attitude towards teaching and learning manual drawing shows that students taught by CAD tend to focus on learning the commands at the expense of the understanding of some fundamental aspects of engineering graphics, projections, conventions and geometric construction. Two possible explanations are that:

- Students consider more appealing to explore the use of software rather than to learn the basics and their attention while learning goes straight forward.
- Students act in response to assessment criteria: if assessment criteria are perceived as related to the mastery in using the software, being students concentrated on developing skills to succeed in the test, they will dedicate less time to rudimentary comprehension (Canty and Seery, 2012).

The question is therefore: assessment criteria related to the use of CAD, are they apt to evaluate the understanding of engineering graphics fundamentals?

#### **3.3.1 Mastering CAD does not imply mastering engineering graphics fundamentals**

Meyers (2000) and McCardle (2002) concur that there is a differentiation between “topics” and “tools”: ‘tools are a means used for learning about the topics’. To be adept at applying a tool does not necessarily imply to master the topic the tool aims to instruct. There are areas of engineering graphics education where CAD is essential, such as computer model application (e.g. Finite element analysis; simulations and graphic presentations; rapid prototyping; design projects and reverse engineering) and computer graphics modelling (e.g. 2-D computer sketching; 3-D modelling techniques; computer assembly modelling; multi-view projection from computer model), as indicated by Barr (2012). For these areas, the ability of using CAD and the mastery of the topics are strongly linked, and the evaluation of the mastery on CAD is therefore a good approximation of the learning level of students. In the area of graphics fundamentals (e.g. Graphics projections; sectioning; dimensioning; engineering graphics) the ability of using CAD and the mastery of the topics are connected, but notably different.

In our previous work (Metraglia et al., 2011), we proposed an instrument to assess and classify the learning of engineering graphics fundamentals - the instrument was named 'Technical Drawing Evaluation Grid (TDEG)' and it has been used at our University for four years in the first-year engineering graphics course. None of the basic engineering graphics skills cited in the Technical Drawing Evaluation Grid refer to skills in using CAD. At the same time, there is an acknowledged shared tool to assess and classify the skills developed through the learning of a CAD: the 2D CAD European Computer Driving License. Such license certifies the abilities in: creating drawings and objects; using selection tools; manipulating objects; and editing drawing properties. None of the skills assessed by this license refer to the basic knowledge and skills in engineering graphics. As a result, we can reason out that mastering CAD is not a synonym of mastering basic engineering graphics skills, and therefore assessing CAD skills is not a synonym of assessing engineering graphics skills.

### **3.3.2 Issues in linking CAD skills and skills in the fundamentals**

The link between CAD skills and skills in the fundamentals gets more complicated if we consider that CAD is not only one: there are many CAD programs. Each faculty usually adopts one or more software in engineering graphics education (e.g. Solidworks, Pro-E, Inventor, Solid Edge,...) and apart from the basic functions shared among all of the CADs, specific procedural command knowledge varies from a CAD software package to another and from one version of CAD to another (Chester, 2007). Students who learn a type of CAD in a faculty, they may develop different skills from students learning some other CAD software in some other faculty. Likewise, students who learn a type of CAD and students learning the same type of CAD only a few years later, they may develop different skills, because of the new releases of software and the increasing number of CAD-related applications software (Field, 2004). Moreover, some faculties may have to pass from a type of CAD to another due to costs related to financing or training opportunities, they may not possess the chance to select the CAD that best goes with the learning outcomes of their programs (Clark and Scales, 2000), or they may not have educational laboratories provided with computers apt to support the latest CAD software. The comparison of skills developed by people using different CADs is therefore a problem, and one of the reasons why an international CAD license was made (the 2D CAD European Computer Driving License aforementioned). At any rate, this kind of assessment concerns the learning of a tool, and not the learning of the language of visualization and communication that is engineering graphics (La Verne and Meyers, 2007, Metraglia et al., 2011).

In sum, the more the assessment of skills concerns the role of the software instead of the master of the graphics basics, the more the students may tend to concentrate on learning the software commands rather than on learning the rules and conventions, particularly the ones CAD allows to skip. The problem is enhanced by the fact that students use different CADs in the various engineering colleges, and it is therefore difficult to make comparisons between the students' level of understanding of fundamentals. Since the assessment of skills in CAD is not an optimal approximation of the understanding of engineering graphics fundamentals, this may explain why novice engineers have problems in understanding and creating drawings remote from CAD, as argued by the industrials interviewed by McLaren (2008).

## **4 DISCUSSION**

Figure 2 graphically represents the desired situation in an Impact Model (indications from Blessing and Chakrabarti, 2009). Compared to the Reference Model in Figure 1, the Impact Model includes the supports, i.e. the solutions proposed, and the desired effects.

The supports are represented as hexagonal elements to distinguish them from the factors shown in the ovals. The links and the signs have been modified to represent the desired effects, and some auxiliary effects of the use of supports have been inserted. Despite Blessing and Chakrabarti (2009) suggest to remove the links that are no longer relevant once the supports have been introduced, we chose to keep them in gray in Figure 1, to allow the reader to value the impact of supports on the existing situation.

The analysis identified three possible reasons why novice engineers may lack in fundamentals.

The first reason relates to the change of the incoming level of first-year engineering students. Most of the students enter engineering colleges without prior experience in engineering graphics and CAD, and they meet difficulties in introductory courses because they lack knowledge in basics of engineering graphics and in the use of software.

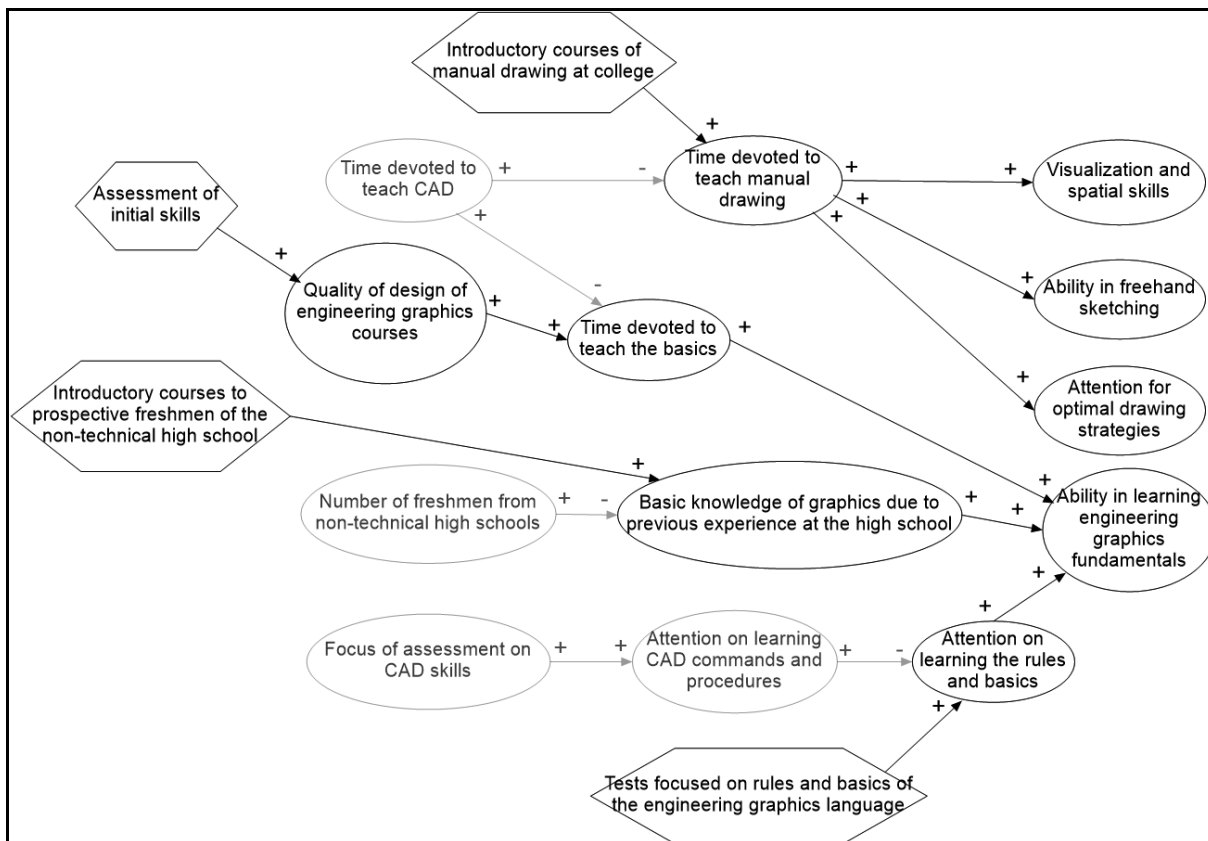


Figure 2. Impact Model showing the desired situation by actuating the proposed solutions

We think that three possible ways to improve the current situation may be:

- Cooperation with high schools, especially non-technical high schools, by proposing introductory engineering graphics courses tailored to high school students interested in attending engineering colleges, so to teach them some of the basics before their entrance at the university. There might not be the possibility to make them as prepared as students from the technical high school, but at least the initial gap between them at the college would be reduced.
- Assessment of engineering graphics skills of students before the beginning of courses at university. This would allow to take a picture of the real level of knowledge of the freshmen and therefore to design the first engineering graphics course by considering the learning outcomes that are reasonably possible to achieve.
- Providing of additional introductory courses at engineering colleges, where students who feel they are weak in the basics can attend integrative lessons to better understand the key concepts of engineering graphics. In some universities of the United States, some courses in beginning graphics are provided as an option for students (Meyers, 2000), and also at the University of Brescia we had a positive experience of a three-weeks introductory course in engineering graphics before the beginning of the first-year lessons.

The second reason identified by the analysis relates to the lack of skills typically developed by manual drawing, such as visualization and spatial skills, abstraction of objects from drawings and ability in freehand sketching. Despite manual drawing is no longer considered important in many engineering graphics courses at the university, the use of CAD in teaching is currently not a full substitute for the development of such skills related to manual drawing. For the growing number of first-year students without prior experience it is very important both to develop such skills and to gain the fundamentals of engineering graphics before approaching CAD (Brown, 2009), also because it is acknowledged that to master the basics facilitates the approach to the software.

We believe therefore that though CAD is essential in engineering graphics education programs, manual drawing has still a role to play, and it needs therefore to be kept in instructional programs, at least in introductory or beginning courses. Once the basics are learned by manual drawing and the skills related have been developed, it is then easier for students to approach CAD and to achieve better results in terms of comprehension and quality of outcomes.



The third reason why novice engineers may lack in fundamentals relates to the way the basics and the knowledge of fundamentals are assessed. In basic engineering graphics courses teaching CAD, students tend to concentrate on the learning of commands and on the mastery of the tool, because the assessment tends to focus on such skills rather than stressing the knowledge of the basics.

We think that two possible ways to improve this situation may be:

- To motivate students to learn the basics by approaching engineering graphics as a language of communication. We stressed this idea in our previous work (Metraglia et al., 2011): for a language, when you know the meaning and the pronunciation of words and you are able to make sentences, then you are able to interact with the rest of the world; in engineering graphics, when you know the drawing rules and regulations and you know how to design drawings for specific goals, then you can use engineering graphics to solve design problems. By focussing on engineering graphics as a language to communicate information, students may be more interested in learning the code of communication, i.e. rules and fundamentals.
- To improve the way engineering graphics skills are assessed. We believe that if the final outcome that is evaluated is the production of a CAD drawing, then students will naturally try to find the quickest way to be able to produce a CAD drawing, and they will therefore dedicate less attention to the steps not leading to such result, included the learning of some basics, as also argued by Cauty and Seery (2012). If the final assessment was related to the mastery of the language, then students may dedicate their attention on the comprehension of the rules of the language and on how to use them to produce good outcomes.

We acknowledge that the assessment of basic engineering graphics skills is a hard matter. In our previous work (Metraglia et al., 2011) we highlighted that beyond the distinction between skills in software and skills in the basics, there is a further distinction between comprehension and production of engineering graphics. Some students may understand very well the basics of drawing and they may be able to read a 2D drawing, but at the same time they may be not good at producing a technical drawing from scratch. On that point are also students who may be able to produce good drawings only because they have memorized a lot of subroutines, but without seeing the principle of such operations. In that sense, in the introductory engineering graphics course of the University of Brescia, we have been trying to assess both the types of skills by introducing questionnaires with basic tasks to be manually achieved - to assess the understanding of the basics -, and the manual production of engineering drawings - to assess the abilities in production. That approach is apparently pushing students to learn the fundamentals of engineering graphics, because they are perceived as necessary to succeed in the assessment.

## **5 CONCLUSION**

Novice engineers result to be skilled in CAD but with lack of fundamentals in engineering design graphics. That could be explained by the fact that:

- Students who currently enter engineering colleges they have less and less prior graphics experience since the number of them who come from non-technical high schools is increasing;
- Freshmen have not the chance to develop the basics and visualization skills because CAD is taught since the beginning of the course and manual drawing is taught little or none;
- The assessment of skills in engineering graphics is misunderstood for assessment of skills in using the CAD software, when such two kinds of skills are linked but not equivalent.

The engineering graphics education of first-year engineering students should therefore take into consideration these issues and look for solutions to improve the learning of such students.

The solutions proposed in this study concern:

- Strengthening of the collaboration with high schools, and particularly with non-technical high schools, by providing additional introductory courses on engineering graphics to be attended before the beginning of the university;
- Adoption of strategies to motivate students to approach to engineering graphics as a language of visualization and communication with rules and standards linked with CAD but distinct from it;
- Assessment of initial skills in order to design introductory courses of engineering graphics focused on the development of solid grounding basics;
- Development of assessment tools aimed to evaluate both comprehension of the fundamentals and skills in producing engineering drawings.

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