AIR PUMP – IMPROVEMENT OF A ‘SKYSCRAPER-TYPE’ EXERCISE FOR MECHANICAL ENGINEERING PROGRAMS

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ABSTRACT

‘Air Pump 2’ is a design-build-test (DBT) exercise at the start of the first-year project module in Mechanical Engineering (ME) at École Polytechnique (EPM). ME students have gained prior experience at ‘Air Pump 1’ 16 weeks before, a playful challenge on Orientation week. In ‘Air pump 2’, teams of 4-6 students work from a ‘functional requirement’ sheet. The context is that of corporations competing for a ‘contract’ for 10,000 pumps. The flow-pressure-volume pre-tests of a prototype, materialised by apparatuses not fully appropriate, set the context for a ‘Test’ phase in two rounds, on ‘new’ and ‘aged’ pumps. Students keep track of test scores and costs (an opportunity to discuss breach of ethical behaviour). A 20 min class reflection follows a first 10 min individual reflection without prompts. On the upside, many students do not take the embedded 10 min break, and work on their pump. On the downside, only a minority pursue the reflection off-hours, and too small a percentage of the pumps bide by the constraints or actually work. Informal surveys point to this as a probable cause of disengagement from subsequent autonomous reflection.

KEYWORDS

Air pump; Design-Build-Test; Experiential learning; Collaborative improvement.

INTRODUCTION

Mechanical engineers often design from functional specifications and reverse engineering, convey their ideas with sketches, make good use of morphological analysis in the selection of a conceptual solution, and weigh their choices between standard and custom-made parts. At EPM, the Mechanical Engineering program sought an alternative to the more Civil Engineering oriented ‘Skyscraper’ DBT exercise known to CDIO regulars [1]. Experimented with in the fall of 2009, ME has since used and improved the ‘Air pump’ every semester (ME has some 200 students incoming in the fall and 50 starting in the winter semesters).

This paper summarises our experience with the ‘Air pump’, a DBT exercise used to help the students develop the tendency to seek structure when learning how to solve problems of all kinds. It reviews reasons in favour of a mechanical system DBT-type exercise, together with the rationale behind its recurrent use. The material conditions under which to carry the exercise follows, with building material, testing apparatuses, and room setup. Group and team sizes, and goal structuring is presented. Finally, results cover the necessities of sketching, the simplification of goals, the multiple ways “creativity” circumvents the basic characteristics of a normal working pump, and weaknesses in the testing apparatuses. Our observations as to the small percentage or pumps that incorporate one-way valves, the even smaller percentage that reasonably work as pumps complete the results, and the outstanding capabilities of students to make the best of this learning situation complete the paper.

REASONS

Why have a son that resembles the father not

The merits of the 'Skyscraper' are unquestionable. Design-Build-Test (DBT) experiences and full courses have been surveyed, and found — over and above the training of design skills — to improve motivation, understanding of engineering, and non-technical skills [2].

An exercise more aligned with the discipline of the junior students, who can then relate more intensely to the design would better secure potential benefits. Although deemed obvious, this statement leaves something to be desired. For instance, too few students appreciate stretching out of their specialty before they actually explore diversity: Mechanical Engineering students dislike having to take Electrical Engineering courses until they discover Mechatronics. Are we to foster monolithic specialties for that reason? Nevertheless, classical Mechanical Engineering deals mostly with powered mechanisms that produce external effects due to moving parts, fluids and the laws of thermodynamics, and the 'Skyscraper' does not share these characteristics.

Air pumps come in a variety of sizes, shapes, concepts (bellows, piston,...) and stroke (single, double). Some hidden constituents are most critical. Volume analysis is within the reach of college students (volume of a cylinder, a cone, a prism,...). Leaks are mostly localised at the interface of moving parts, unless the pump is ill assembled. Pumps can be easily tested for flow, pressure and volume, and accommodate multiple technical criteria as goals. Pumps can be made to satisfy complementary functional requirements ("must be aesthetical",...). Constraints can be imposed (minimum cubic centimetres displaced per stroke,...).

Air pumps provide the opportunity to present the problem as a case of functional analysis. The students design, build, and test a mechanism. They conceive from a description of the needs expressed as the result of a functional analysis: primary and complementary functions, constraints, and functional criteria. Students being "exposed to" functional analysis adds to the merits of the DBT (and they could be "exposed to" multiple-criteria based goal-equation optimisation and risk assessment).

Why the early bird catches the worm

Upon entering university, students commit themselves to the unknown, gradually discover a new learning environment, and decode the characteristics — one by one — of a new context they must integrate quickly. As a source of difficulties, students work mainly from preliminary *a priori* representations of the expectations. Some advocate that the earlier the student can validate and calibrate these representations, the easier and more successful his adaptation will be. A significant DBT provides a meaningful and comprehensive exercise to challenge these representations early in the curriculum.

The first day of Orientation week capitalises on 'Air Pump 1' as a relaxed playful challenge. Forced randomness in the formation of teams ensures that new students mingle. Senior students act as mentors. First year teachers stand by the test stands for the pumps, break the ice, and question the students about their pumps and tests. The exercise has the new students gather a common experience over which to present the curriculum at the end of "first day". This common-experience-based questioning and presentation also should help the students start calibrating their *a priori* representations of our expectations.

The first day of the introductory project module one semester later builds on 'Air pump 2': an immediate, structured, and criteria-based design-build-test exercise, starting from the tabular output of a functional analysis. It thereafter forms the basis of the presentation about the project module. Again, we hope a common-experience-based reflection and presentation will help students to build teams with a common representation of our expectations in the module.

Why twice offer the same snare to the fox

Every student enters ‘Air pump 2’ with the prior experience of ‘Air pump 1’, where the forced randomness of team memberships reasonably ensures that different prior designs of Orientation week are regrouped at the onset of ‘Air pump 2’. New teams start with multiple concepts to describe, discuss, compare, and choose from. A context normally created by brainstorming and morphological analysis, when methodology replaces the availability of prior designs. Group behaviour in ‘Air pump 2’ is thus kin to *acceleration by apprenticeship*.

From Gray and Feldman [3], the success of *apprenticeship* rests on a tendency to acquire knowledge and develop skills through interactions with more competent team members, and on a preference to perform new tasks in collaboration with others before trying them on our own. With respect to any of the prior design — taken separately — one mate is a “more competent team member”. All thus have equal opportunity to enjoy the status. Only communication and teamwork skills, and not the absence of prior knowledge, would then determine team dynamics... given prior designs all had equal value.

The well-known aspects of *work*, *affection*, and *power* (*achievement*, *affiliation*, and *power*) affect individuals and groups. S. Landry proposes a model postulating these aspects translate into dynamic zones, the chaotically-cyclical evolution of the group thus taking specific stakes into account as the group travels in and migrates between these three zones, until *group convergence* into a working merged zone has occurred [4]. First occurrences are not very efficient in a group. By repeating an exercise that students can trace to a playful context, and by helping provide “equal opportunity” about the potential contribution of all in the group, we hope to alleviate the contrary effects of the initial state of *divergence*, within a team that has not yet developed its group culture.

SETUP

“In my mind’s eye, Horatio”

Building material

Building material should allow multiple concepts and not only geometrical variations over a single concept. Two concepts easy to implement are ‘piston-’, and ‘bellows-pumps’. Piston-pumps are easy to build from balls of Styrofoam and cardboard cores from rolls of disposable paper sponge-towels (choose balls that are undersized with respect to the ID of the rolls). Bellows-pumps are easy to make from large coffee paper-cups and 2 litres freezer plastic-bags (have ‘small’, ‘medium’, and ‘large’ paper-cups for geometrical variations).

Allow for variations in size by making available raw sheets of thin (cheap) ‘artist’s cardboard’ that can be cut to shape and size; coffee cups becoming the ‘piston’. Long wooden stir-sticks will make handles and rods once assembled in bundles. Cores of sponge-towels rolls will find their way as handles and rods for the bigger piston-pumps. For bellows-pumps, think not the design will restrict itself to a freezer bag caught between two coffee cups: stir-sticks become as good stiffening ribs as imaginative cuts of raw cardboard sheets do.

All this creativity being saved by... duct-tape. Make it an expensive item at the store. It is difficult to sell duct-tape by the yard. Buy small 7-meter reels at the general store; use a balance from the chemistry-lab that can measure to the 1/100 g; sell full reels of tape; have the teams cost their pump by weighing the tape used to the fraction of a gram. Duct-tape weighs approximately 8.6 g/m. Get statistics from single source supplies, and always use the same balance. It does not matter if they cheat; just keep in mind to talk about bankruptcy and repercussions on retirement funds, when a corporation gets its success from hiding its true costs to itself or to the stockholders.

Figure 1. Basic material, and many rolls of duct-tape to save the day

Not too fancy testing apparatuses

Call it 'pressure test' — Make water-column manometers from plywood, tygon-tubing and a plastic ruler (tilt them to an angle for the pumps that cannot deliver any pressure, so students will nevertheless witness some visual repercussion). All the piston-pumps being leaky, define 'success' by water height & time: "holding 10 cm of water for 6 sec." Beware of squirts, and run the output of the manometer spout into an overflow bottle. "What are we testing exactly?" warrants being part of the reflection phase.

Call it 'volume-test' — Materialise fixed volumes from empty boxes of photocopy-paper. Fill about two-thirds of the box with books about hand-pumps, and put a plastic garbage-bag in the remaining cavity. Tape the opening of the garbage bag around a 30 cm length of tygon-tubing (prepare many bags this way, to just switch bags between teams). Define 'volume filled' as the state of the bag that will just begin to lift a piece of light cardboard laid across the top of the opened box. Teams keep track of the 'time to inflate'.

Call it 'flow-test' — Have rows of 9 to 16 candles ready to be blown. This is a most popular test, so make matches handy. Keep this an open-air test, at the mercy or cross-flows from the air conditioning and all. Then, of course: "What are we testing exactly?"

All tests suffer from uncontrollable extraneous factors, and leaks develop in two test beds. The stage is set for a fruitful discussion about the pitfalls of writing down "test" in a specification, rather than investing time and effort to think of some set of quantitative criteria.

Teams and Coaching

As in the 'Skyscraper' DBT exercise, teams of four to five form at random (seven is a crowd). A ratio of ~60 participants for three to four instructors satisfies peaks. It is best for two of the instructors to know the exercise in depth, the other(s) having received only a short set of rules or being mid-curriculum students that have participated in the past.

Adjust the coaching style to your goals. 'Design' may or may not be the primary one.

DBT room setup

It is wise to distribute the instruction sheets after a short introductory talk. Save your work surfaces: do not distribute X-acto knives ahead of time. Do so one by one, insisting that only light 'in-hands' cutting is done at the tables. Have scissors for every table. Save your methodology: only have secondary school geometry kits and drawing sheets ready at the tables. The rest is a source of distraction.

As shown in Figure 2, the ‘Store’ should have displays where participants can come and look at the material (think of it as a catalogue). Exploration by handling and getting the feel for hardness, rigidity, resistance to tears, etc. requires the purchasing of the wanted material. Have trays ready (the tops of the photocopy-paper boxes). ‘Purchasing agents’ all come in a very short time span and the store needs good organisation. Have two cutting stations ready at the store, to handle all cutting done by resting the knives on a surface.

Figure 2. Work and ‘stockroom’ tables for a group of 50 split in 10 teams of five.

“By indirections find directions out”

Set the goals as you would functional specifications. Avoid text, and use a table to present principal and complementary functionalities, and constraints. Use some equation to compute the ‘merits’ of the different pumps. Something like:

$$P\ V = n\ R\ T \tag{1}$$

is a nice one to start with, without considering costs, where:

- P price you are willing to pay for the pump,
- n number of candles blown in the line-up,
- R height of water column maintained for t sec
- V volume inflated,
- T time to inflate volume V.

Once experienced, change the equation by removing the budget limit, and making *cost* one of the parameters in the equation. Let the teams decide the design they should favour to optimise ‘merits’ with cost included. (Then discuss ‘risk aversion’ and the psychology of engineers; hesitations or discomfort, effects of problem “framing” in relation to the position of people in the Kolb quadrants of experiential learning or to the Myers-Briggs indicators.)

A criterion easy to set, that rules out some of the detailed designs and none of the concepts, is *volume displaced per stroke*: it can be that cores of sponge-towel rolls satisfy the volume limit at full length, but not the *volume displaced* with a piston inside. Make economic use of these ‘traps’ with groups of less than 20 teams, as students oversee them easily. ‘Traps’ make the need to analyse very relevant though.

A sound suggestion is often to “get out of one’s office, and go see on the shop floor or in the field.” Have many sizes of tygon-tubing at the store, as an opportunity to put the good word to work. Make connections to two of the test beds by tight-fit insertion of tygon-tubing of matching ID/OD. Let the teams *get out of their office*, and find by themselves what size they should buy. Put many ID/OD on display, and deliver at random when teams do not specify ID or OD sizes on their purchasing list.

The enthusiasm at the ‘volume test’ tends to age the pumps quickly. The result of the ‘pressure test’ may consequently depend on testing sequence. Rule this out by imposing a sequence, or let the teams decide what sequence they should use to maximise their gains.

Do not exaggerate with this spirit of ‘indirections’. Teams are finding their way through enough confusion as it is. You may consider it sufficient for them to have thought about the question. Decide whether answers are ‘free’ or, as for a consultant, provided for a charge.

RESULTS

Students responded well and involved themselves genuinely in both ‘Air pump 1’ and ‘2’, as a Conceive-Design-Implement-Operate compact exercise (see Figure 3 and Table 1).

Figure 3. Conceive - Design - Implement - Operate the 'Air pump'

“I must be cruel, only to be kind”

The students did not appreciate the necessity of analysis first hand. They did not readily see the merits of producing sketches of their concept(s) either. The second may lead to the first: mechanical analysis often rests on a good visual model, and appreciation of the phenomena present; bad graphical representations of a situation often result in poor analysis.

To allow the purchasing of building material without a proper sketch of the concept(s) at hand is to pave the way to chaos, or at least for the team budget to go astray. Building results in makeshift improvisation with little future into it. To request an R & D plan for the purchasing of R & D material is for you to decide: too many rules and too much structure sometimes impede the initial ‘spark’ of actually trying. In our view, it is preferable for ‘something’ actually to happen for discussion to build on, although we fully realise it may result in technical failure.

The choice to make depends on your goals, and may well be different for ‘Air pump 2’ (within a project module) than it is for ‘Air pump 1’ (Orientation week).

It was a pump; “take it for all in all”

Technical requirements already overwhelm the teams. Think twice before imposing complementary functions like ‘To be aesthetically pleasing’. Stick to technical functions unless the teams incorporate students from a commercial design school or faculty.

We know it is difficult to deal with non-technical complementary functions like aesthetics in a design, when firstly trained only with technical criteria. Think of your bookcase as a student however: it started with 12 bricks and 3 wooden planks, and only later did it become Poul Hundevad’s ‘HU’ bookcase cabinet in rosewood veneer. Begin with the ‘bricks’ and ‘planks’.

Yet "... know a hawk from a handsaw."

Depending on your tolerance, choose the extent to which you announce what are ‘Aye-pumps’ and what are ‘Nay-pumps’. Do not trust the student’s implicit assumptions will be your own: write them down.

It is surprising how creativity compares between ‘designing a pump’ and ‘bending natural assumptions’. Be ready for everything and anything, and realise ahead of time students have great difficulties in knowing how to fit implicit assumptions when given functional requirements: they think in terms of ‘solutions’.

“Do you think I am easier to be played on than a pipe?”

A very popular natural design is the ‘valve less ten-fingers-two-mates-operated-pump’: as one member of the team actuates the strokes, another is supposed to rest his fingers on intake holes and pinch some restriction to the nozzle, all with appropriate synchronisation and synchronicity. A free entertainment no professor can forget.

The constraint “Operated by a single individual” usually takes care of the matter. Yet, ...

"... let the candied tongue lick absurd ‘pumps’"

The design that then becomes popular is the ‘bagpipe-pump’. One or two pieces of tygon-tubing and a freezer-bag will do it. The single orifice ‘pump’ has to be repeatedly connected and disconnected to its point of use. When disconnected, the operator puts the nozzle into his mouth and blows into the bag. He then plugs the nozzle with his thumb. The tricky part is to reconnect the nozzle to the point of use ..., so maybe you just hold it close. Then fit the bag under your armpit, and press with your upper arm while your hands are busy with the nozzle and the connecting intake of the apparatus. Did you not know that makes a pump?

A constraint like “... maintaining connection” usually closes the gap in the rules. When present, the ‘volume-test’ also winnows the wheat, separating the good grain from the chaff: not maintaining the connection considerably lengthening the time to inflate.

"Our wills and fates do so contrary run
That our devices still are overthrown"

The test beds develop leaks. They develop on manometers of the ‘pressure-test’ when quick disconnect couplings are handled to reset the volume of water to its initial value after a pressure surge has caused the water to squirt into the safety bottle. They develop at the seam between the bag and the tygon-tubing of the ‘volume-test’ when students press the bag too firmly to empty it. These weaknesses did not cause strong discontent.

Table 1.
Summary of results for Orientation week and First project module

CDIO-*R*	First day of Orientation week (Semester 1)	First day of 1^{rst} Project module (Semester 2)
General purpose	Have new students create bonds; create a base to present curriculum	Create a common base to present the module, and to reference to thereafter
Mode	Playful challenge	Criteria based DBT
Teams	Forced randomness across groups (3 gr. of 60) and teams (4 to 6 per team)	Determined by group schedule (3 gr. of 55), spontaneous team (~5 per team)
Tests (intent)	Number *n* of blown candles in line, Height *h* of water maintained for *T* sec, Time *t* to inflate bag of volume *V* cm^3	Number *n* of blown candles in line, Height *h* of water maintained for *T* sec, Time *t* to inflate bag of volume *V* cm^3
Tests (truth...)	Other activities of Orientation week cause the curtailment of full testing	Often have to curtail; Too long to inflate 10,000~15,000 cc; Candle blowing and Water column trigger much interest
Prior attitude	Relaxed, Perplexed, Happy to mix, and to have a hands-on exercise	Expectant (students now know ahead of time); May arrive prepared (may be beneficial to force random teams again)
Ice-breaker	Yes, Structured	No, Left to the initiative of the team
Initial material conditions	Instructions and geometric drawing kits on tables; Cutting tools distributed with verbal reminder of written precautions	Tools on tables (no expenditures); Material as visual display only; Think of safety glasses
Some possibilities and constraints	Roaming mentors ask for (and help do) sketching; Material supplied as per itemised list ("open bar", keep track of usages); Hints peppered around	R/D purchases possible; Must produce & document concept before purchasing material to build; Material supplied as per "purchasing list" (no real BOM)
Conceive *(They have learned!)*	Long silent hesitations; Frequent visits to material 'stock-room'; Usually retain first idea; Team easily follows any idea voiced with conviction; Little if any purchases for R/D exploration; All teams take about the same time ± 20%	(15 min) Discussions start in 1 min; Compare different prior experiences; Poor writing in log book but various rough sketches on separate sheets; Strong feelings about feasibility; Some teams take twice the time of others
Design *(They have not learned that much!)*	No real design nor analysis; No usage of cut views given, showing valves for single and double stroke air pumps (ignorant about the relevancy of hints)	(25 min) Some deepening of concepts; No analysis (at most compute volume of cylinder); No track of thoughts about leaks; Some concerns about valves
Implement *(They have not learned at all!)*	Wide variations from team to team (gender, cultural,...); Makeshift job (decide as you go); Very little task distribution / parallelism; Enthusiasm	(25 min) Wide variations from team to team (gender, cultural,...); Makeshift job (decide along); Little task distribution / parallelism; Enthusiasm; Will skip break
Operate (test)	Expectant; Interests all team mates; Discussion with standing professor[(a)];	(2 × 10 min + 10 min break between runs) Expectant; Interests all; Desire to redesign; Skip break; Should age pump by 100 strokes during break (not done)
***R*eflect**	None asked	(30 min) Self & in group (participate verbally: 1/8, non verbally: 1/4, 'pump in hand': 1/8); Finish at home (no marks)
Follow up (on Reflect)	Satisfaction survey: ~85% (not about the quality of design, of design process or of teamwork)	From individual log books, sample of ~25 over ~150 (see Table 2)

A permanent assembly will solve leaks at the manometers, allowing for its replenishment from the opening to the safety bottle. Making a number of bags ready so all can be deflated slowly will easily solve leaks at the bags. The blowing of candles do not present surprises nor weaknesses; the students find it impressive, and take pleasure in blowing as many as they can (even lining-up multiple rows into a single one) should the pump survive the test or not.

Nothing "is rotten in the state of Denmark"

Persevere. You will witness major technical improvements in 'Air pump 2' from 'Air pump 1'. As the news spreads about 'Air pump 2', students actually prepare for it. Impose the random formation of teams to avoid students neatly producing designs beforehand.

There is no reduction of interest. Free-style surveys include positive or no comments at all about the 'Air pump', and no negative comments. The absence of negative remarks is significant in itself, as other exercises do get negative comments from some students.

An on-hours individual, written reflection closes the exercise (no marks, nor prompts about topics to reflect on). All logbooks were globally evaluated four to nine weeks after 'Air pump 2'. The first, second and third quartile boundaries were computed. The written on-hours reflection about 'Air pump 2' was examined in detail on three 4% samples of logbooks, each taken from the vicinity of quartile boundaries. Table 2 shows compact free translations (not verbatim) statements from this 12% sample, mostly from the first and second quartile boundaries. Students around the third quartile were satisfied with descriptions rather than reflections. An 'off-hours' reflection exercise was not so successful, except for a few students. The technical performance of the pump had little impact on the quality of the reflection.

In one group, the instructors misinterpreted the goals of the reflective phase. They revealed a numbered list of prompts beforehand. A sample of 15 log-books again taken in the vicinities of the three quartile boundaries then shows the vast majority of comments to be strictly descriptive, and the students to be satisfied by 'ticking the list' instead of thinking and making links. Tipping off students seems to have an adverse effect on the quality of the reflection.

"Find out the cause of this effect,
Or rather say, the cause of this defect,
For this effect defective comes by cause."

"Alas, poor Yorick!"

On Orientation week, 'Air pump 1' only have 10% to 15% of the pumps with attempted tilting disk valves, the majority being 'piston pumps' (see Figure 4). As semesters pass, First project module pumps have had about the same, then an increase in (unsuccessful) attempts to assemble complicated ball check-valves (see Figure 5) with 'piston pumps', and —recently— an abrupt change of popularity towards 'bellows pumps' with or without valves. Hallway discussions probably fuel these bulk trends, as there is nothing more public than a secret inside a classroom. It remains that students seem unable to appreciate the meaning of 'airproofness' in practical terms.

Some instructors suggest the failure to be "catalectic" in nature: students would simply not have experienced with one-way valves, and be strangers to the concept. They suggest the introduction of a visual apparatus with flipper-gates and rolling marbles the students could tilt back and forth. In their view, watching the marbles go from A, passing the gate to B, and then passing the second gate to C, will have the students grasp a missing concept. The students would then transfer the concept to pumps, where molecules replace marbles.

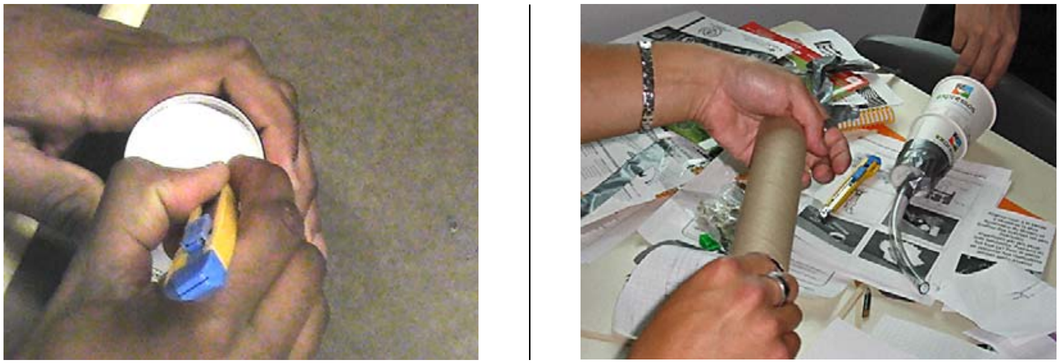

Figure 4. First generation attempts at making one-way tilting disk valves

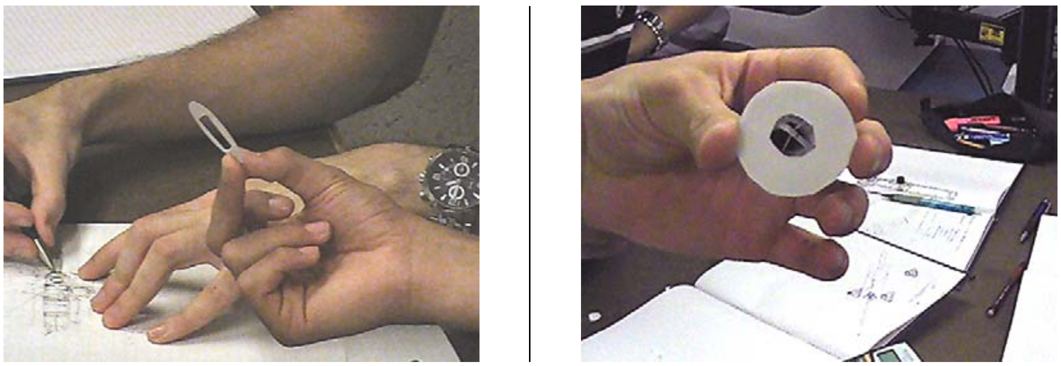

Figure 5. Second generation attempts at making ball check-valves

We tend to believe the concept does not pose problems. We speculate that the undisciplined nature and the unwillingness of a physical apparatus to behave the way it “should” has itself become a mere concept, and is practically strange to them. Introductory science courses used to mark the end of magical thoughts. However, the tendency to replace physical benches with simulators might now fuel them. Students could grasp the simulated concepts and nothing more, nothing that — by unplanned chance — might have been conveyed by the physical nature of the bench. When interpreting a ‘real world situation’, maybe it simply does not cross their mind that a pressure drop increases as a restriction lengthens (unless this was specifically simulated), that poor joints become reasonable ones given enough overlap. Students seem to hope molecules will not circumvent a Styrofoam ball resting on a hole cut by hand in the bottom of a paper cup. Trying to breathe through a thin straw might be a better initiation to reality, than having marbles roll past a flipper-gate.

“(Do) We go to gain a little patch of ground,
That hath in it no profit but the name(?)”

As much from the free-style surveys about the exercises as from the samples from the log-books, students appear to find enough benefits from the ‘Air pump’ not to report discontent nor suggestions about technical improvements. The current quality and quantity of reflections do not seem to correlate with pumps actually functioning the way pumps should.

It may be appropriate to question our desire to see (say) 30% to 40% of the constructions actually be classical pumps, with intake and outtake valves. Are students not wiser in taking the exercise in a more global perspective, and in finding benefits and intellectual nourishment outside of the realm of technically sound pumps? Just what additional benefits must one secure from a single exercise, once it has delivered advantages in all the contents of Table 2?

Table 2.
Sampled testimonies (12%) from individual on-hours reflection exercise (no prompts)

“I should take care in following guidelines. I don’t take enough time to develop my ideas, to really understand before I go into action.” *“I should trust a decision when it was carefully made by the group, not jam the brakes.”* *“Had we built on the contributions of all, we would have had an advantage in optimisation.”*
“We didn’t respect the constraints (difficult).” [Unspecified difficulty: is it in ‘respecting’ or is it the ‘constraints’ given on the instruction sheet?](a) *“We really need to make use of everyone’s ideas, to discuss, to refer to criteria (anticipate advantages and disadvantages) for the thing to go forward.”* *“What could have we done to foresee technical conclusions (max-min, friction, jamming)”*
“Too obsessed by ‘piling-up stuff’; take more time to imagine / create => cohesion.” *“Good to retain the simplest idea after all is said and thought.”* *“We discovered potential improvements after building... nothing left on budget by then.”*
“Brainstorm.” “Distribute tasks.” “Make a better job at designing.” [Triple underline for last]
[Task distribution: only descriptive, no conclusion. Followed by text under.] *“Our analysis was so weak, inexistent. We relied on past experience though. But we went for the detailed design too soon, without an idea of what we were going for.”* *“Why were we so inefficient? What to do and how to do, to avoid such inefficiencies?”*(b)
“That design was not efficient. Needed technical modifications (the valves are critical).”(c) *“It would have been important to define the steps we went through to avoid confusion.”*
“Learn how to sketch. Sketching is the best way to communicate your ideas.” *“Design – Take time, foresee repercussions before you build.”* *“Tasks – Share. It’s important.”*
“My contribution was dispersed around. We broke into sub-groups without coordination.” *“When it has to work, ‘technical consensus’ ≠ ‘democratic voting’: got to be systematic.”*(d)
[ONE (1) student in 150, but mostly after seeing the late prompts] *“We haven’t been honest / ethical in our tests and calculations (pretending). It wasn’t planned dishonesty, just ‘happened’. Not ‘OK’ nevertheless.”* *“I tried to share and assign jobs, but was overcome by another wanting to lead.”* *“Sure, there were some isolated ideas that took us forward. But the bulk of the thrust came from sharing ideas. That, we could do thanks to different prior experiences.”* *“From the start, we lined-up all the ideas from the prior experiences. Could then choose more easily. I analysed some of the suggestions, and found not all had been foreseen.”* *“I acted positively, but I did not encourage anyone. Took too much time to control time.”* *“I didn’t do something from A to Z. Jumping around. So was everybody. In the future, we must assign jobs and keep members accountable. That should help efficiency.”* *“I suggested ideas based on first-principles. Not all were good, but we could tell why.”* *“We took risks without checking: a plastic bag ages rapidly. Explore with facts.”* [etc.] [Above is roughly half of what was reflected individually, after seeing the prompts. About the same content as other students before seeing the prompts. Only approx. 10% of students somewhat deepened their reflection after seeing the prompts.]

(a) Author’s comments in brackets within the cells of Table 2.
(b) Same student would repeatedly ‘admit being at fault’ in exercises where he was asked to ‘give feedback’ to teammates.
(c) At every ‘Air pump 1’, the vast majority of pumps do not have one-way valves. At ‘Air pump 2’, ~30% of teams try to ‘negotiate’ for valve less “inflatable bag-pipes”.
(d) Shows the confusion that can arise after being instructed on ‘transferable skills’.

CONCLUSION

This paper presented a new DBT exercise better aligned with the discipline of Mechanical Engineering. Orientation week and the first project module of the curriculum make use of it. Inexpensive building material easily accommodates the two concepts of piston- and bellows-pumps, with a wide variety of sizes and shapes. Testing apparatuses must be prepared in advance, and the results of the three tests (flow, pressure, and volume), either single or statistical, can determine "performance" by the use of a compounding equation. Results over four semesters show the same technical weaknesses in prior knowledge from the part of the students. The percentage of pumps that perform well enough over all three tests is half of what was hoped. Nevertheless, not only is there no strong sign of adverse effects on the motivation or willingness of students to carry out the assignment, but undirected individual reflection appear to harvest all that would be expected of a DBT exercise.

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"Beggar that I am, I am [not] poor in thanks."

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"The rest is silence." (William Shakespeare, Hamlet 5.2)

REFERENCES

[1] Frey, D., Crawley, E., "Skyscraper Project Based Learning Experience (v. 3.0)". [On line.] Available: http://www.cdio.org/knowledge-library/documents/skyscraper-exercise.

[2] Malmqvist J., Young P.W., Hallström S., Kuttenkeuler J., Svensson T., "Lessons Learned From Design-Build-Test-Based Project Courses", International Design Conference - Design 2004, Dubrovnik, May 18 - 21, 2004.

[3] Gray P. and Feldman J., "Playing in the Zone of Proximal Development: Qualities of Self-Directed Age Mixing between Adolescents and Young Children at a Democratic School", American Journal of Education, Vol. 110, February 2004, pp. 108-145.

[4] Landry S., "Ch. 12 – Le mouvement d'intégration en spirale du groupe restreint, de son émergence à sa dissolution", Travail, affection et pouvoir dans les groupes restreints — Le modèle des trois zones dynamiques, PU Québec – Gestion, 2007.

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