# Using Fluid Power in the Middle-School Classroom

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In middle-school classrooms syringe fluidics can be used in different ways to deliver STEM content and practices.

## Introduction:

Fluid power activities can be accomplished using syringes filled with air or with water to simulate cylinders acting pneumatically or hydraulically.  These mechanical and fluid power systems apply a significant number of scientific and technological concepts and can be constructed using readily available materials at a reasonable cost.

The delivery mechanism is inquiry led for scientifically orientated environments, design led for technically orientated environments. The STEM content and practices that will be met by students using these approaches are many and integral. For example, students will inquire into scientific concepts such as energy transfer and loss, pressure or particle theory of gases and liquids, and/or, engage in engineering practices and employ technological concepts such as force, mechanical advantage or work done. They will also use a variety of mathematical skills while doing so such as determination of the mean, exploring linear and non-linear functions or determining the area and volume of solids.

## Basics of Fluid Power

Air and water may be used safely in syringes in the middle school classroom. Air and water are both fluids and they have different densities and different properties. Greater pressures may be achieved using water and therefore a larger potential for work, while air is more convenient but a “spongy” or compressible fluid compared to water. Students soon discover this and tend to move towards syringes filled with water as these cylinders are easier to control.

The Designed World especially Industry and Agriculture use fluidics extensively. The fluid normally used in hydraulic systems is oil. It is retained in the “closed system” moving through manifolds, controlled valves and actuating cylinders that vary in size according to their purpose. Compare, for example, micro cylinders used in the finger joints of a robotic hand with the macro cylinders seen on huge construction machinery. Pneumatic systems, on the other hand, tend to be "open" and a good deal noisier than their hydraulic counterparts. Their reservoir of air is the atmosphere. An example of a full scale pneumatic manufacturing system at the LEGO® factory in Billund, Denmark was available twenty-five years ago. Pneumatic power took grains of colored plastic and transformed into those small and familiar figures at the other end of the line!

Oriented towards Science:

One way to deliver STEM content and practice that is more "scientific" in nature is to use a rig that holds different sizes of cylinders in place while subjected to different forces. In other words, this would be a device to hold a syringe upright while a mass is applied to its plunger. An interesting and technological diversion at this point is to have the students design the rig! In this case the engineering criteria would include the need to hold cylinders of different cross-sectional areas and volumes upright – say 10cc, 20cc, 30cc and 60cc – in a structure that would allow a mass of 750 grams to be applied to the plunger. (In case you don't feel inclined to make these, such rigs are commercially available.)

The scientific content is organised within "Physical Science" core ideas such as "Energy", "Matter, and Energy" or "Fluids". Here are some examples of these core ideas:

*A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (NRC, 2011)*

> PS2.A – "Any two interacting objects exert forces of equal magnitude on each other in opposite directions (Newton's third law). The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change.
>
> PS3.B – "When the motion energy of an object changes, there is inevitably some other change in energy at the same time. For example, to make an object start moving or to keep it moving when friction forces transfer energy away from it energy must be provided … "
>
> PS3.C – "When two objects interact, each one exerts a force on the other and these forces can transfer energy between them."

*Benchmarks for Science Literacy (AAAS, 1993)*

4E/M4 – "Energy appears in different forms and can be transformed within a system."

The detailed science content covered while investigating fluid power using the rigs I designed includes: investigation of frictional forces inherent in the rig system, inquiring into the relationship between the load required to overcome frictional resistance and the cross sectional area of different sized syringes, investigation of forces in the system when the driving and driven cylinders are the same size and different sizes, calculating pressure (Pa) in system using force measured in N and area measured in $m^2$, exploring Pascal's Principle, using water instead of air as the medium in the syringes, investigating the work done in different systems and, investigating mechanical advantage and mechanical efficiency by using two rigs as a hydraulic jack system.

The mathematical content includes calculation of the internal circumference and cross-sectional area of different sized syringes, calculation of the mean of different readings, deduction of linear $y = mx + c$ relationships and operating with imperial and metric units and exponential notations.

A good number of mathematics standards included the following, applicable to students in grades 6 to 8:

*Principles and Standards for School Mathematics – Standards For Grades 6-8 (NCTM, 2000)*

Number and Operations Standard **-** develop an understanding of large numbers and recognize and appropriately use exponential, scientific, and calculator notation;

Algebra Standard **–** identify functions as linear or nonlinear and contrast their properties using tables, graphs, or equations;

Measurement Standard **–**develop strategies to determine the surface area and volume of selected prisms, pyramids, and cylinders

## Engineering Design and Technological Systems:

Another way of bringing fluidics into the classroom is to introduce the students to a variety of pneumatically driven systems, or sub-systems using the concept of a pneumatic arm. The three essential movements required for any arm are rotation from side to side, movement up and down and a "grabber" or claw arrangement. This route would be favored by a classroom whose focus was not on scientific content and practices but on engineering design and technological systems.

The exploration of the sub-systems of a robotic arm and the design and manufacture of a system to undertake a specific design task involve a large number of standards for technological literacy for middle school grades:

*Standards For Technological Literacy (ITEA/ITEEA, 2007)*

Standard 2: Students will develop an understanding of the core concepts of technology –

> 2-V. Controls are mechanisms or particular steps that people perform using information about the system that causes systems to change.

Standard 8: Students will develop an understanding of the attributes of design –

> 8-G. Requirements for design are made up of criteria and constraints.

Standard 9: Students will develop an understanding of engineering design –

> 9-H. Modeling, testing, evaluating, and modifying are used to transform ideas into practical solutions.

Standard 11. Students will develop the abilities to apply the design process –

> 11- L. Make a product or system and document the solution.

Standard 16. Students will develop an understanding of and be able to select and use energy and power technologies –

> 16-G. Power is the rate at which energy is converted from one form to another or transferred from one place to another, or the rate at which work is done.

Through the NFPA Education and Technology Foundation four “classroom” kits are available at reasonable cost. They are a rotational arm kit, a lifter kit, a rotating base kit and a clamp kit and they are suitable for a small group of students. Wood glue, the recommended adhesive for the structural cardboard gusset system, is not included. Scissors are the only other requirement. Downloadable instructions are available in PowerPoint format and these are easy to follow.

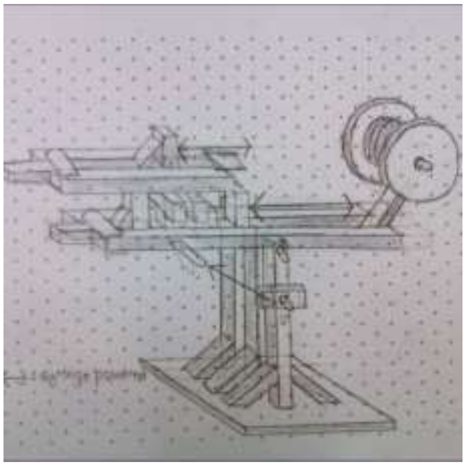
The students built three different kits following the instructions and were able to have working models in an hour (clamp and rotating arm) or two (lifter). The kits demonstrated the three essential movements and prompted discussions about improving the design of each, especially the rotational arm kit, as what was soon discovered was a need for a rotating base upon which a structure could be mounted that would house actuating cylinders. The students did not use the rotating base kit that was also available.

The natural progression from the three kits is a pneumatically driven arm capable of picking up an object and placing it accurately elsewhere. At this point a design problem was introduced to the students - a device to pick up an object and place it accurately on one of two shelves – a problem scenario downloaded from the NFPA website. The criteria the model should meet were determined and the students set about the challenge. It is important to note that no one group ended up with a design that was the exactly the same as another.

*A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (NRC, 2011)*

> ETS1.A: “The more precisely a design task’s criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions.”
>
> ETS1.B: “A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. Sometimes parts of different solutions can be combined to create

> a solution that is better than any of its predecessors. In any case, it is important to be able to communicate and explain solutions to others."



STEM content and practices:

The two approaches to introducing fluidics into a middle school classroom cited above support and complement each other. Both approaches are available, according to the circumstances within a school, ideally by a science teacher (who might cover technological science) or a technology teacher (who might also teach physical science). However, many middle school teachers, these days, are responsible for teaching more than one subject area while some middle schools have a science specialist or technology specialist responsible for teaching all students in a particular grade or all the middle school grades.

Whatever the environment there is a great opportunity to dialogue and discover more about the implementation of STEM practices. What is the common content and what are the common practices in the STEM subject areas? In other words, what knowledge, concepts and skills are delivered by each of the STEM subjects? These are the questions of current interest and a good deal of support is becoming available, for example in *"A Framework for K-12 Science Education" (NRC, 2011, BOX ES.1)*

## The Fluid Power Challenge:

The NFPA Education and Technology Foundation is a 501 (c) (3) tax-exempt charitable organization that supports educational programs and research in fluid power. On its website teachers can find details of Fluid Power Challenges – a culminating activities that may be "run" in-house or on a larger scale between schools in the same school district or different school districts.

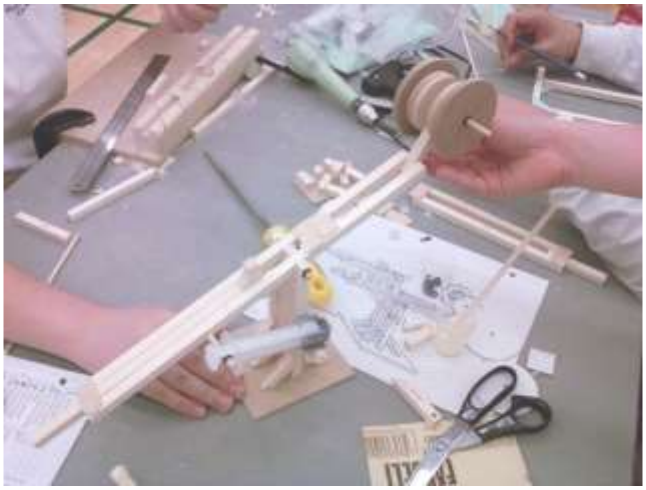
Every year the Foundation posts a different Fluid Power Challenge for middle-school students in teams of four. They encourage mixed teams of boys and girls although the winners of one of the local events organised in 2011 was an all-girls team. They provide details of how to organise a Challenge and comprehensive support for organisers and facilitators.

A school can download the Challenge and use it in-house. The format the NFPA uses for the larger local challenges is a Workshop day followed, some weeks later, by the Challenge day. For a classroom that has been engaged in either or both of the approaches above, the Challenge would provide a good culminating activity for the students especially the requirement to produce a design portfolio from which a "final" device was built a week after the Challenge was introduced.

In their larger local format, students attend a Workshop day where they are introduced to the techniques of building pneumatic devices powered by syringes and the method of construction using wooden pieces and cardboard gussets as well a safety procedures e.g. wearing safety glasses when cutting and drilling. They are introduced to industrial applications of fluidics (a downloadable video) and converse with members of the NFPA who work in the industry and have given their encouragement to the project and with faculty members who are hosting the event. They are also introduced to the Challenge they will face on the Challenge day.

Between the Workshop day and the Challenge day they take away the models they have made and a kit of tools and materials. They must use the resources in the kit to investigate possible solutions to the

Challenge and document their work in a portfolio. On the Challenge day, three or four weeks later, they return to the venue with only their portfolio and their tool kit. At the event they use the same set of materials they took to their schools after the workshop and the design work in their portfolio to build their device to meet the Challenge. They have 3 – 4 hours to build, test and adjust their device.

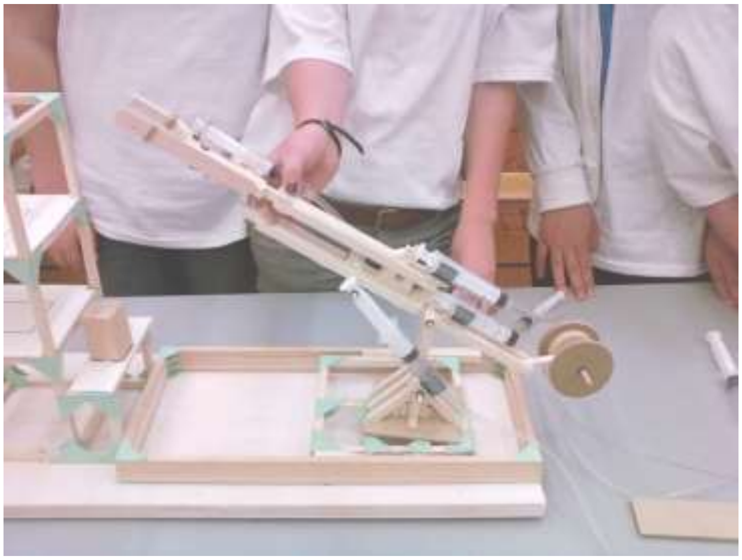


The overall evaluation is comprehensive including teamwork skills, the design and the performance of their finished device and their portfolio, the latter constituting 35% of their overall score:

| | **Part A: PORTFOLIO** | | |
|---|---|---|---|
| ***Evaluation criteria*** | **5** | **3** | **1** |
| Co-operation of team members in production of portfolio & planned production of their device | All team members participated in a material way and were familiar with portfolio contents and all offered answers to questions | Most team members participated but one or two were not very familiar with portfolio contents | Portfolio was done completely by one student; other team members not at all familiar with portfolio contents |
| At least two sketches and an isometric drawing of a small portion of a device properly dimensioned | Two detailed sketches and an isometric drawing properly dimensioned and of high quality | Two sketches and an isometric drawing of fair quality with some correct dimensioning | One or two low-quality sketches and no isometric drawing |
| An orthographic drawing showing dimensions and construction notes | The orthographic drawing shows front, side and plan views and is set out so the scaled dimensions relate to the views | Three orthographic drawings are presented showing front, side and plans views using an inconsistent scale | Only one of three orthographic drawings are available |
| A list of materials including consideration of alternatives | A comprehensive list of materials is provided, including dimensions and alternative materials are discussed that are "outside the box" | An incomplete list of materials is provided without dimensions and alternative materials are discussed that are much the same as provided | No list of materials or alternatives are provided |

| | | | |
|---|---|---|---|
| Description of the use of the principles of structural strength and stability | Uses 5 terms from the following sets: force or load or compression or tension; symmetry or triangulation; center of gravity or balance and counterbalance; support beams or struts; gusset or joining methods; aesthetics | Uses 3 terms from the following sets: force or load or compression or tension; symmetry or triangulation; center of gravity or balance and counterbalance; support beams or struts; gusset or joining methods; aesthetics | Uses 1 term from the following sets: force or load or compression or tension; symmetry or triangulation; center of gravity or balance and counterbalance; support beams or struts; gusset or joining methods; aesthetics |
| Explanation of the placement of fluid systems | Uses 5 terms from the following sets: pneumatic and hydraulic; system or input and output; density or particle theory; pressure or Pascal's principle; lever or pivot; friction; work done or mechanical advantage | Uses 3 terms from the following sets: pneumatic and hydraulic; system or input and output; density or particle theory; pressure or Pascal's principle; lever or pivot; friction; work done or mechanical advantage | Uses 1 term from the following sets: pneumatic and hydraulic; system or input and output; density or particle theory; pressure or Pascal's principle; lever or pivot; friction; work done or mechanical advantage |
| Evaluation of a prototype including conclusions from making it | A good description of two prototypes and thorough documentation of lessons learned including reasons for choosing one of the prototypes | A fair description of a prototype and poor documentation of lessons learned | No mention of prototype or conclusions |
| | **Part B: TEAMWORK SKILLS** | | |
| ***Evaluation criteria*** | ***5*** | ***3*** | ***1*** |
| Members of the group work independently and co-operatively | All team members work co-operatively sharing the workload in a planned way by working in pairs and individually | 3 team members work co-operatively sharing the workload by working in pairs and individually. One team member participates minimally | 1 team member does most of the work on their own with the remaining members participating minimally |
| Safe working practices | Team members wear safety glasses while cutting and drilling using the appropriate tools safely with material held in a secure way | Team members wear safety glasses while cutting or drilling using the inappropriate tools with material held in an insecure way | No team members wears safety glasses while cutting or drilling |
| | **Part C: DEVICE DESIGN AND OPERATION** | | |
| ***Evaluation criteria*** | ***5*** | ***3*** | ***1*** |
| The system is well constructed | The system has all parts securely built and attached. The materials involved are used efficiently | The system has most parts securely built and attached. Breakage occurs when force is applied to the fluid subsystems | The system has few parts securely built and attached and it does not function |
| A number of actions of the device are controlled by hydraulics | Four intact | Two intact | None |

| | | | |
|---|---|---|---|
| A number of students operate the device without “breakage” | Four (one may give directions to the other 3) | Two | None |
| **TOTAL TEAM SCORE:** | **SUMMATION OF SCORES** | | |
| | Portfolio (35) | Teamwork (10) | Interview Questions (20) |
| | | | |
| | Device Design and Operation (15) | Points accumulated in designated time period | |
| | | | |



Each local event is sponsored by a NFPA member company and this school year over 600 students have been involved. A great deal is achieved at the Foundation’s Challenge, summarized in part below:

> *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (NRC, 2011)*
>
> Core Idea ETSC1.C - Optimizing the Design Solution: “There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. Comparing different designs could involve running them through the same kinds of tests and systematically recording the results to determine which design performs best. Although one design may not perform the best across all tests, identifying the characteristics

> of the design that performed the best in each test can provide useful information for the redesign process, i.e. some of those characteristics may be incorporated into the new design. This iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution. Once such a suitable solution is determined, it is important to describe that solution, explain how it was developed, and describe the features that make it successful."

## Conclusion:

In a middle school classroom the science of fluidics was introduced using the rig. Afterwards the students were able to make informed choices about using air or water as the medium inside their syringes. The three kits available through the NFPA were explored, reverse-engineered, discussed and analyzed as a lead into the in-house culminating activity: the design of a warehouse shelving system. Hand tools and safety glasses were already available so the only cost involved was the NFPA Challenge kit for each team of four students. The vital element of the portfolio work made this an excellent culminating activity covering many elements of STEM curricula as attested by the standards addressed in this article.

The students demonstrated great ingenuity and inventiveness when faced with the open-ended design problem. They retained and used the scientific content in their explanations in their portfolios and used acquired engineering practices in the technological design process.

One female student expressed it in a nutshell:

"… now I know how to analyze a problem and how to think".

References :

American Association for the Advancement of Science (AAAS) (1993) Benchmarks for Science Literacy. Oxford University Press Inc.

International Technology Engineering Educators Association (ITEA/ITEEA) 3rd edition (2007) Standards For Technological Literacy

National Council of Teachers of Mathematics (NCTM) (2000) Principles and Standards for School Mathematics – Standards For Grades 6-8

NFPA Education and Technology Foundation http://www.nfpafoundation.org/About/Index.aspx Information about the NFPA Challenge Kits and their Grant Program is available at http://www.nfpafoundation.org/FPChallenge/ChallengeGrantProgram.aspx

National Research Council. (2011). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas.* Committee on a Conceptual Framework for New K-12 Science Education Standards. Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press. Prepublication edition.

Portfolio "Criteria For Success" available from author

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Pic1: Isometric drawing of proposed model

Pic2: Construction of prototype

Pic3: Testing the model

Pic4: Meeting the Challenge