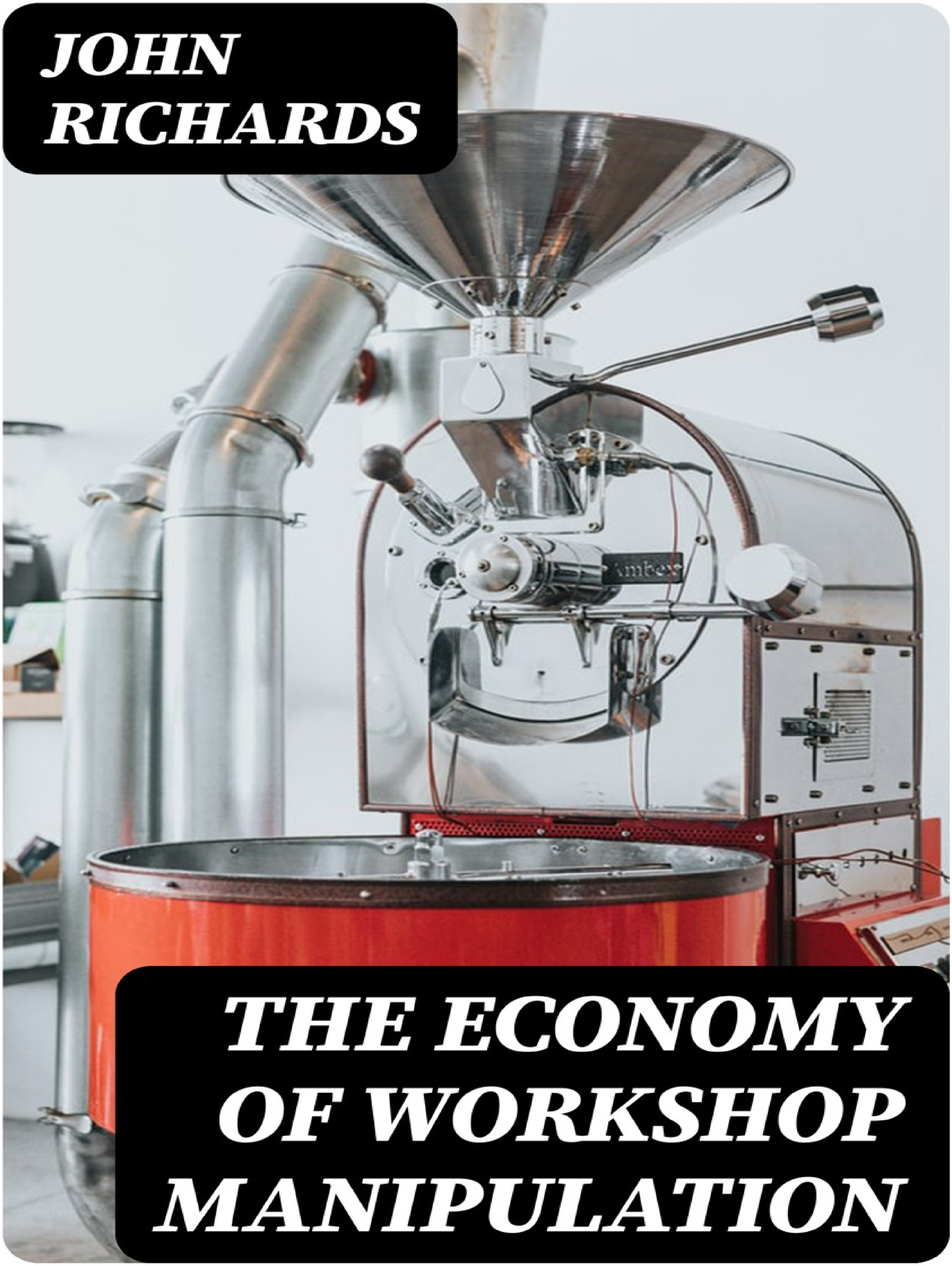
JOHN RICHARDS

THE ECONOMY OF WORKSHOP MANIPULATION



John Richards

The Economy of Workshop Manipulation

A logical method of learning constructive mechanics. Arranged with questions for the use of apprentice engineers and students

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PREFACE.

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The contents of the present work, except the Introduction and the chapter on Gauges, consist mainly in a revision of a series of articles published in "Engineering" and the Journal of the Franklin Institute, under the head of "The Principles of Shop Manipulation," during 1873 and 1874.

The articles alluded to were suggested by observations made in actual practice, and by noting a "habit of thought" common among learners, which did not seem to accord with the purely scientific manner in which mechanical subjects are now so constantly treated.

The favourable reception which the articles on "Shop Manipulation" met with during their serial publication, and various requests for their reproduction in the form of a book, has led to the present edition.

The addition of a few questions at the end of each chapter, some of which are not answered in the text, it is thought will assist the main object of the work, which is to promote a habit of logical investigation on the part of learners.

It will be proper to mention here, what will be more fully pointed out in the Introduction, that although workshop processes may be scientifically explained and proved, they must nevertheless be learned logically. This view, it is hoped, will not lead to anything in the book being construed as a disparagement of the importance of theoretical studies.

Success in Technical Training, as in other kinds of education, must depend greatly upon how well the general mode of thought among learners is understood and followed; and if the present work directs some attention to this matter it will not fail to add something to those influences which tend to build up our industrial interests.

J. R.

10 John Street, Adelphi,
London, 1875.

THE ECONOMY
OF
WORKSHOP MANIPULATION.

INTRODUCTION.

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In adding another to the large number of books which treat upon Mechanics, and especially of that class devoted to what is called Mechanical Engineering, it will be proper to explain some of the reasons for preparing the present work; and as these explanations will constitute a part of the work itself, and be directed to a subject of some interest to a learner, they are included in the Introduction.

First I will notice that among our many books upon mechanical subjects there are none that seem to be directed to the instruction of apprentice engineers; at least, there are none directed to that part of a mechanical education most difficult to acquire, a power of analysing and deducing conclusions from commonplace matters.

Our text-books, such as are available for apprentices, consist mainly of mathematical formulæ relating to forces, the properties of material, examples of practice, and so on, but do not deal with the operation of machines nor with constructive manipulation, leaving out that most important part of a mechanical education, which consists in special as distinguished from general knowledge.

The theorems, formulæ, constants, tables, and rules, which are generally termed the principles of mechanics, are in a sense only symbols of principles; and it is possible, as many facts will prove, for a learner to master the theories and symbols of mechanical principles, and yet not be able to turn such knowledge to practical account.

A principle in mechanics may be known, and even familiar to a learner, without being logically understood; it might even be said that both theory and practice may be learned without the power to connect and apply the two things. A person may, for example, understand the geometry of tooth gearing and how to lay out teeth of the proper form for various kinds of wheels, how to proportion and arrange the spokes, rims, hubs, and so on; he may also understand the practical application of wheels as a means of varying or transmitting motion, but between this knowledge and a complete wheel lies a long train of intricate processes, such as pattern-making, moulding, casting, boring, and fitting. Farther on comes other conditions connected with the operation of wheels, such as adaptation, wear, noise, accidental strains, with many other things equally as important, as epicycloidal curves or other geometrical problems relating to wheels.

Text-books, such as relate to construction, consist generally of examples, drawings, and explanations of machines, gearing, tools, and so on; such examples are of use to a learner, no doubt, but in most cases he can examine the machines themselves, and on entering a shop is brought at once in contact not only with the machines but also with their operation. Examples and drawings relate to *how* machines are constructed, but when a learner comes to the actual operation of machines, a new and more interesting problem is reached in the reasons *why* they are so constructed.

The difference between *how* machinery is constructed and *why* it is so constructed, is a wide one. This difference the reader should keep in mind, because it is to the second query that the present work will be mainly addressed. There will be an attempt—an imperfect one, no doubt, in some cases—to deduce from practice the causes which have led to certain forms of machines, and to the ordinary processes of workshop manipulation. In the mind of a learner, whether apprentice or student, the strongest tendency is to investigate why certain proportions and arrangement are right and others wrong—why the operations of a workshop are conducted in one manner instead of another? This is the natural habit of thought, and the natural course of inquiry and investigation is deductive.

Nothing can be more unreasonable than to expect an apprentice engineer to begin by an inductive course in learning and reasoning about mechanics. Even if the mind were capable of such a course, which can not be assumed in so intricate and extensive a subject as mechanics, there would be a want of interest and an absence of apparent purpose which would hinder or prevent progress. Any rational view of the matter, together with as many facts as can be cited, will all point to the conclusion that apprentices must learn deductively, and that some practice should accompany or precede theoretical studies. How dull and objectless it seems to a young man when he toils through "the sum of the squares of the base and perpendicular of a right-angle triangle," without knowing a purpose to which this problem is to be applied; he generally wonders why such puzzling theorems were ever invented, and what they can have to do with the practical affairs of life. But if the same learner were to happen upon a builder squaring a foundation by means of the rule "six, eight, and ten," and should in this operation detect the application of that tiresome problem of "the sum of the squares," he would at once awake to a new interest in the matter; what was before tedious and without object, would now appear useful and interesting. The subject would become fascinating, and the learner would go on with a new zeal to trace out the connection between practice and other problems of the kind. Nothing inspires a learner so much as contact with practice; the natural tendency, as before said, is to proceed deductively.

A few years ago, or even at the present time, many school-books in use which treat of mechanics in connection with natural philosophy are so arranged as to hinder a learner from grasping a true conception of force, power, and motion; these elements were confounded with various agents of transmission, such as wheels, wedges, levers, screws, and so on. A learner was taught to call these things "mechanical powers," whatever that may mean, and to compute their power as mechanical elements. In this manner was fixed in the mind, as many can bear witness, an erroneous conception of the relations between power and the means for its transmission; the two things were confounded together, so that years, and often a lifetime, has not served to get rid of the idea of power and mechanism being the same. To such teaching can be traced nearly all the crude ideas of mechanics so often met with among those well informed in other matters. In the great change from empirical rules to proved constants, from special and experimental knowledge to the application of science in the mechanic arts, we may, however, go too far. The incentives to substitute general for special knowledge are so many, that it may lead us to forget or underrate that part which cannot come within general rules.

The labour, dirt, and self-denial inseparable from the acquirement of special knowledge in the mechanic arts are strong reasons for augmenting the importance and completeness of theoretical knowledge, and while it should be, as it is, the constant object to bring everything, even manipulative processes, so far as possible, within general rules, it must not be forgotten that there is a limit in this direction.

In England and America the evils which arise from a false or over estimate of mere theoretical knowledge have thus far been avoided. Our workshops are yet, and must long remain, our technological schools. The money value of bare theoretical training is so fast declining that we may be said to have passed the point of reaction, and that the importance of sound practical knowledge is beginning to be more felt than it was some years ago. It is only in those countries where actual manufactures and other practical tests are wanting, that any serious mistake can be made as to what should constitute an education in mechanics. Our workshops, if other means fail, will fix such a standard; and it is encouraging to find here and there among the outcry for technical training, a note of warning as to the means to be employed.

During the meeting of the British Association in Belfast (1874), the committee appointed to investigate the means of teaching Physical Science, reported that "the most serious obstacle discovered was an absence from the minds of the pupils of a firm and clear grasp of the concrete facts forming a base of the reasoning processes they are called upon to study; and that the use of text-books should be made subordinate to an attendance upon lectures and demonstrations."

Here, in reference to teaching science, and by an authority which should command our highest confidence, we have a clear exposition of the conditions which surround mechanical training, with, however, this difference, that in the latter "demonstration" has its greatest importance.

Professor John Sweet of Cornell University, in America, while delivering an address to the mechanical engineering classes, during the same year, made use of the following words: "It is not what you 'know' that you will be paid for; it is what you can 'perform,' that must measure the value of what you learn here." These few words contain a truth which deserves to be earnestly considered by every student engineer or apprentice; as a maxim it will come forth and apply to nearly everything in subsequent practice.

I now come to speak directly of the present work and its objects. It may be claimed that a book can go no further in treating of mechanical manipulation than principles or rules will reach, and that books must of necessity be confined to what may be called generalities. This is in a sense true, and it is, indeed, a most difficult matter to treat of machine operations and shop processes; but the reason is that machine operations and shop processes have not been reduced to principles or treated in the same way as strains, proportions, the properties of material, and so on. I do not claim that manipulative processes can be so generalised—this would be impossible; yet much can be done, and many things regarded as matters of special knowledge can be presented in a way to come within principles, and thus rendered capable of logical investigation.

Writers on mechanical subjects, as a rule, have only theoretical knowledge, and consequently seldom deal with workshop processes. Practical engineers who have passed through a successful experience and gained that knowledge which is most difficult for apprentices to acquire, have generally neither inclination nor incentives to write books. The changes in manipulation are so frequent, and the operations so diversified, that practical men have a dread of the criticisms which such changes and the differences of opinion may bring forth; to this may be added, that to become a practical mechanical engineer consumes too great a share of one's life to leave time for other qualifications required in preparing books. For these reasons "manipulation" has been neglected, and for the same reasons must be imperfectly treated here. The purpose is not so much to instruct in shop processes as to point out how they can be best learned, the reader for the most part exercising his own judgment and reasoning powers. It will be attempted to point out how each simple operation is governed by some general principle, and how from such operations, by tracing out the principle which lies at the bottom, it is possible to deduce logical conclusions as to what is right or wrong, expedient or inexpedient. In this way, it is thought, can be established a closer connection between theory and practice, and a learner be brought to realise that he has only his reasoning powers to rely on; that formulæ, rules, tables, and even books, are only aids to this reasoning power, which alone can master and combine the symbol and the substance.

No computations, drawings, or demonstrations of any kind will be employed to relieve the mind of the reader from the care of remembering and a dependence on his own exertions. Drawings, constants, formulæ, tables, rules, with all that pertains to computation in mechanics, are already furnished in many excellent books, which leave nothing to be added, and such books can be studied at the same time with what is presented here.

The book has been prepared with a full knowledge of the fact, that what an apprentice may learn, as well as the time that is consumed in learning, are both measured by the personal interest felt in the subject studied, and that such a personal interest on the part of an apprentice is essential to permanent success as an engineer. A general dryness and want of interest must in this, as in all cases, be a characteristic of any writing devoted to mechanical subjects: some of the sections will be open to this charge, no doubt, especially in the first part of the book; but it is trusted that the good sense of the reader will prevent him from passing hurriedly over the first part, to see what is said, at the end, of casting, forging, and fitting, and will cause him to read it as it comes, which will in the end be best for the reader, and certainly but fair to the writer.

CHAPTER I.
PLANS OF STUDYING.

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By examining the subject of applied mechanics and shop manipulation, a learner may see that the knowledge to be acquired by apprentices can be divided into two departments, that may be called general and special. General knowledge relating to tools, processes and operations, so far as their construction and action may be understood from general principles, and without special or experimental instruction. Special knowledge is that which is based upon experiment, and can only be acquired by special, as distinguished from general sources.

To make this plainer, the laws of forces, the proportion of parts, strength of material, and so on, are subjects of general knowledge that may be acquired from books, and understood without the aid of an acquaintance with the technical conditions of either the mode of constructing or the manner of operating machines; but how to construct proper patterns for castings, or how the parts of machinery should be moulded, forged, or fitted, is special knowledge, and must have reference to particular cases. The proportions of pulleys, bearings, screws, or other regular details of machinery, may be learned from general rules and principles, but the hand skill that enters into the manufacture of these articles cannot be learned except by observation and experience. The general design, or the disposition of metal in machine-framing, can be to a great extent founded upon rules and constants that have general application; but, as in the case of wheels, the plans of moulding such machine frames are not governed by constant rules or performed in a uniform manner. Patterns of different kinds may be employed; moulds may be made in various ways, and at a greater and less expense; the metal can be mixed to produce a hard or a soft casting, a strong or a weak one; the conditions under which the metal is poured may govern the soundness or shrinkage,—things that are determined by special instead of general conditions.

The importance of a beginner learning to divide what he has to learn into these two departments of special and general, has the advantage of giving system to his plans, and pointing out that part of his education which must be acquired in the workshop and by practical experience. The time and opportunities which might be devoted to learning the technical manipulations of a foundry, for instance, would be improperly spent if devoted to metallurgic chemistry, because the latter may be studied apart from practical foundry manipulation, and without the opportunity of observing casting operations.

It may also be remarked that the special knowledge involved in applied mechanics is mainly to be gathered and retained by personal observation and memory, and that this part is the greater one; all the formulæ relating to machine construction may be learned in a shorter time than is required to master and understand the operations which may be performed on an engine lathe. Hence first lessons, learned when the mind is interested and active, should as far as possible include whatever is special; in short, no opportunity of learning special manipulation should be lost.

If a wheel pattern come under notice, examine the manure in which it is framed together, the amount of draught, and how it is moulded, as well as to determine whether the teeth have true cycloidal curves.

Once, nearly all mechanical knowledge was of the class termed special, and shop manipulations were governed by empirical rules and the arbitrary opinions of the skilled; an apprentice entered a shop to learn a number of mysterious operations, which could not be defined upon principles, and only understood by special practice and experiment. The arrangement and proportions of mechanism were also determined by the opinions of the skilled, and like the manipulation of the shop, were often hid from the apprentice, and what he carried in his memory at the end of an apprenticeship was all that he had gained. The tendency of this was to elevate those who were the fortunate possessors of a strong natural capacity, and to depress the position of those less fortunate in the matter of mechanical "genius," as it was called. The ability to prepare proper designs, and to succeed in original plans, was attributed to a kind of intuitive faculty of the mind; in short, the mechanic arts were fifty years ago surrounded by a superstition of a different nature, but in its influences the same as superstition in other branches of knowledge.

But now all is changed: natural phenomena have been explained as being but the operation of regular laws; so has mechanical manipulation been explained as consisting in the application of general principles, not yet fully understood, but far enough, so that the apprentice may with a substantial education, good reasoning powers, and determined effort, force his way where once it had to be begged. The amount of special knowledge in mechanical manipulation, that which is irregular and modified by special conditions, is continually growing less as generalisation and improvement go on.

Another matter to be considered is that the engineering apprentice, in estimating what he will have to learn, must not lose sight of the fact that what qualifies an engineer of to-day will fall far short of the standard that another generation will fix, and of that period in which his practice will fall. This I mention because it will have much to do with the conceptions that a learner will form of what he sees around him. To anticipate improvement and change is not only the highest power to which a mechanical engineer can hope to attain, but is the key to his success.

By examining the history of great achievements in the mechanic arts, it will be seen that success has been mainly dependent upon predicting future wants, as well as upon an ability to supply such wants, and that the commercial value of mechanical improvements is often measured by conditions that the improvements themselves anticipate. The invention of machine-made drills, for example, was but a small matter; but the demand that has grown up since, and because of their existence, has rendered this improvement one of great value. Moulded bearings for shafts were also a trifling improvement when first made, but it has since influenced machine construction in America in a way that has given great importance to the invention.

It is generally useless and injudicious to either expect or to search after radical changes or sweeping improvements in machine manufacture or machine application, but it is important in learning how to construct and apply machinery, that the means of foreseeing what is to come in future should at the same time be considered. The attention of a learner can, for example, be directed to the division of labour, improvements in shop system, how and where commercial interests are influenced by machinery, what countries are likely to develop manufactures, the influence of steam-hammers on forging, the more extended use of steel when cheapened by improved processes for producing it, the division of mechanical industry into special branches, what kind of machinery may become staple, such as shafts, pulleys, wheels, and so on. These things are mentioned at random, to indicate what is meant by looking into the future as well as at the present.

Following this subject of future improvement farther, it may be assumed that an engineer who understands the application and operation of some special machine, the principles that govern its movements, the endurance of the wearing surfaces, the direction and measure of the strains, and who also understands the principles of the distribution of material, arrangement, and proportions,—that such an engineer will be able to construct machines, the plans of which will not be materially departed from so long as the nature of the operations to which the machines are applied remain the same.

A proof of this proposition is furnished in the case of standard machine tools for metal-cutting, a class of machinery that for many years past has received the most thorough attention at the hands of our best mechanical engineers.

Standard tools for turning, drilling, planing, boring, and so on, have been changed but little during twenty years past, and are likely to remain quite the same in future. A lathe or a planing-machine made by a first-class establishment twenty years ago has, in many cases, the same capacity, and is worth nearly as much in value at the present time as machine tools of modern construction—a test that more than any other determines their comparative efficiency and the true value of the improvements that have been made. The plans of the framing for machine tools have been altered, and many improvements in details have been added; yet, upon the whole, it is safe to assume, as before said, that standard tools for metal-cutting have reached a state of improvement that precludes any radical changes in future, so long as the operations in metal-cutting remain the same.

This state of improvement which has been reached in machine-tool manufacture, is not only the result of the skill expended on such tools, but because as a notable exception they are the agents of their own production; that is, machine tools produce machine tools, and a maker should certainly become skilled in the construction of implements which he employs continually in his own business. This peculiarity of machine-tool manufactures is often overlooked by engineers, and unfair comparisons made between machines of this class and those directed to wood conversion and other manufacturing processes, which machinists, as a rule, do not understand.

Noting the causes and conditions which have led to this perfection in machine-tool manufacture, and how far they apply in the case of other classes of machinery, will in a measure indicate the probable improvements and changes that the future will produce.

The functions and adaptations of machinery constitute, as already explained, the science of mechanical engineering. The functions of a machine are a foundation on which its plans are based; hence machine functions and machine effect are matters to which the attention of an apprentice should first be directed.

In the class of mechanical knowledge that has been defined as general, construction comes in the third place: first, machine functions; next, plans or adaptation of machines; and third, the manner of constructing machines. This should be the order of study pursued in learning mechanical manipulation. Instead of studying how drilling-machines, planing-machines or lathes are arranged, and next plans of constructing them, and then the principles of their operation, which is the usual course, the learner should reverse the order, studying, first, drilling, planing, and turning as operations; next, the adaptation of tools for the purposes; and third, plans of constructing such tools.

Applied to steam-engines, the same rule holds good. Steam, as a motive agent, should first be studied, then the operation of steam machinery, and finally the construction of steam-engines. This is a rule that may not apply in all cases, but the exceptions are few.

To follow the same chain of reasoning still farther, and to show what may be gained by method and system in learning mechanics, it may be assumed that machine functions consist in the application of power, and therefore power should be first studied; of this there can be but one opinion. The learner who sets out to master even the elementary principles of mechanics without first having formed a true conception of power as an element, is in a measure wasting his time and squandering his efforts.

Any truth in mechanics, even the action of the "mechanical powers" before alluded to, is received with an air of mystery, unless the nature of power is first understood. Practical demonstration a hundred times repeated does not create a conviction of truth in mechanical propositions, unless the principles of operation are understood.

An apprentice may learn that power is not increased or diminished by being transmitted through a train of wheels which change both speed and force, and he may believe the proposition without having a "conviction" of its truth. He must first learn to regard power as a constant and indestructible element—something that may be weighed, measured, and transmitted, but not created or destroyed by mechanism; then the nature of the mechanism may be understood, but not before.

To obtain a true understanding of the nature of power is by no means the difficulty for a beginner that is generally supposed ; and when once reached, the truth will break upon the mind like a sudden discovery, and ever afterwards be associated with mechanism and motion whenever seen. The learner will afterwards find himself analysing the flow of water, the traffic in the streets, the movement of ships and trains; even the act of walking will become a manifestation of power, all clear and intelligible, without that air of mystery that is otherwise inseparable from the phenomena of motion. If the learner will go on farther, and study the connection between heat and force, the mechanical equivalent of heat when developed into force and motion, and the reconversion of power into heat, he will have commenced at the base of what must constitute a thorough knowledge of mechanics, without which he will have to continually proceed under difficulties.

I am well aware of the popular opinion that such subjects are too abstruse to be understood by practical mechanics—an assumption that is founded mainly in the fact that the subject of heat and motion are not generally studied, and have been too recently demonstrated in a scientific way to command confidence and attention; but the subject is really no more difficult to understand in an elementary sense than that of the relation between movement and force illustrated in the "mechanical powers" of school-books, which no apprentice ever did or ever will understand, except by first studying the principles of force and motion, independent of mechanical agents, such as screws, levers, wedges, and so on.

It is to be regretted that there have not been books especially prepared to instruct mechanical students in the relations between heat, force, motion, and practical mechanism. The subject is, of course, treated at great length in modern scientific works, but is not connected with the operations of machinery in a way to be easily understood by beginners. A treatise on the subject, called

"The Correlation and Conservation of Forces," published by D. Appleton & Co. of New York, is perhaps as good a book on the subject as can at this time be referred to. The work contains papers contributed by Professors Carpenter, Grove, Helmholtz, Faraday, and others, and has the advantage of arrangement in short sections, that compass the subject without making it tedious.

In respect to books and reading, the apprentice should supply himself with references. A single book, and the best one that can be obtained on each of the different branches of engineering, is enough to begin with. A pocket-book for reference, such as Molesworth's or Nystrom's, is of use, and should always be at hand. For general reading, nothing compares with the scientific and technical journals, which are now so replete with all kinds of information. Beside noting the present progress of engineering industry in all parts of the world, they contain nearly all besides that a learner will require.

It will be found that information of improvements and mechanical progress that a learner may gather from serial publications can always be exchanged for special knowledge in his intercourse with skilled workmen, who have not the opportunity or means of reading for themselves; and what an apprentice may read and learn in an hour can often be "exchanged" for experimental knowledge that has cost years to acquire.

(1.) Into what two divisions can a knowledge of constructive mechanics be divided?—(2.) Give an example of your own to distinguish between special and general knowledge.—(3.) In what manner is special knowledge mostly acquired?—(4.) What has been the effect of scientific investigations upon special knowledge?—(5.) What is meant by the division of labour?—(6.) Why have engineering tools been less changed than most other kinds of machinery during twenty years past?—(7.) What is meant by machine functions; adaptation; construction?—(8.) Why has the name "mechanical powers" been applied to screws, levers, wedges, and so on?—(9.) Can power be conceived of as an element or principle, independent of mechanism?

CHAPTER II.
MECHANICAL ENGINEERING.

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This work, as already explained, is to be devoted to mechanical engineering, and in view of the difference of opinion that exists as to what mechanical engineering comprehends, and the different sense in which the term is applied, it will be proper to explain what is meant by it here.

I am not aware that any one has defined what constitutes civil engineering, or mechanical engineering, as distinguished one from the other, nor is it assumed to fix any standard here farther than to serve the purpose of explaining the sense in which the terms will be used; yet there seems to be a clear line of distinction, which, if it does not agree with popular use of the terms, at least seems to be furnished by the nature of the business itself. It will therefore be assumed that mechanical engineering relates to dynamic forces and works that *involve machine motion*, and comprehends the conditions of machine action, such as torsional, centrifugal, intermittent, and irregular strains in machinery, arising out of motion; the endurance of wearing surfaces, the constructive processes of machine-making and machine effect in the conversion of material—in short, agents for converting, transmitting, and applying power.

Civil engineering, when spoken of, will be assumed as referring to works that do not *involve machine motion*, nor the use of power, but deal with static forces, the strength, nature, and disposition of material under constant strains, or under measured strains, the durability and resistance of material, the construction of bridges, factories, roads, docks, canals, dams, and so on; also, levelling and surveying. This corresponds to the most common use of the term civil engineering in America, but differs greatly from its application in Europe, where civil engineering is understood as including machine construction, and where the term engineering is applied to ordinary manufacturing processes.

Civil engineering, in the meaning assumed for the term, has become almost a pure mathematical science. Constants are proved and established for nearly every computation; the strength and durability of materials, from long and repeated tests, has come to be well understood; and as in the case of machine tools, the uniformity of practice among civil engineers, and the perfection of their works, attest how far civil engineering has become a true science, and proves that the principles involved in the construction of permanent works are well understood.

To estimate how much is yet to be learned in mechanical engineering, we have only to apply the same test, and when we contrast the great variance between the designs of machines and the diversity of their operation, even when applied to similar purposes, their imperfection is at once apparent. It must, however, be considered that if the rules of construction were uniform, and the principles of machine operation as well understood as the strength and arrangement of material in permanent structures, still there would remain the difficulty of adaptation to new processes, which are continually being developed.

If the steam-engine, for instance, had forty years ago been brought to such a state of improvement as to be