Title: Even gifted students can not see the wood for the trees
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Even gifted students can not see the wood for the trees

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Abstract. Since the very beginning of Petnica Science Center students do small research projects in order to learn the basic scientific methodology. Preparing reports and papers is unavoidable part of such learning. After 25 years of work, it is perfectly clear that students learned how to present their results and write papers. However, such results do not tell us anything about the students' understanding of the broader context of research problem and their attitude toward research process. We believe there is a plenty of room to make progress here.

Keywords. learning through research, science education, scientific method, Petnica

Introduction

Main goal of Petnica Science Center (PSC) is to provide facilities and stimulating surrounding for advanced education and scientific research. All parts of the research process are prepared and monitored by PSC associates. Their task is to advise and guide students through the research [1]. They are, also, supposed to "catalyze" process of research, because we don't have years at disposal, but only a few weeks. However, research has to be student's deed as much as possible. Otherwise, they miss pleasure, satisfaction for well accomplished job. Important feature of those projects is that they do not require full comprehension of complicated concepts of contemporary science and heavy mathematical apparatus. They demand creativity and teamwork.

Probably, the most important part of programs in Petnica concerns methodology of scientific work and writing of science reports and papers - Learning through Research (LTR). This way participants of Petnica programs study by "discovering" various facts, relationships, structures or models under the supervision of more experienced researchers. School curricula cannot keep up with the current flood of information so we have to focus on a few specific students' capabilities; to know how to observe and access information, how to evaluate its content and credibility and how to infer its consequences and possible meanings.

Learning through Research enables three important components in the process of acquiring of knowledge. The first one is an opportunity to "discover". The second one is an opportunity to implement new science in order to examine well-known fact or principle. Thus, we get results which, of course, don't have to be numbers seen for the first time. Passion and excitement of discovery are more important. The third component provides young people with greater responsibility for their own learning. LTR model is individually oriented and all students are supposed to realize how important their own initiative is. Our

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job is to prepare them for individual work. Students have to develop a skill of "navigation" through the ocean of resources and to learn how to learn more efficiently [2].

All students are required to make final reports on their research whether their experiments succeeded or not. Research level of those papers is less important then the fact that job is done completely, not just exciting part, i.e. research itself, but boring part all the way to collecting references and correction of text corrected so many times before.

Drawing from comics "La Vie au Grand Air"

Fig. 1. Teaching of scientific method is always hard

Selected students' papers are published annually in edition called Petnica's Papers since 1992 [3, 4]. Ten years later, Petnica has started with students' science conference [5] in order to give students a chance to present their work in front of their colleagues and get significant feedback. So far, Petnica's Papers had nearly a thousand students' papers in fifteen scientific disciplines. All this material enabled us to see common problems with comprehension of scientific work and students' attitude toward topic of research, science, colleagues, prospective career, etc.

1. Top ten unrelenting problems of LTR

1.2 The lack of hypotheses and educated guesses

If you observe research of students in spectrum of disciplines ranging from mathematics (formal) to ethnology (descriptive), it is likely that most of them could not recognize hypotheses in their work. It is logical consequence of more practical problem that students are not comfortable to use educated guesses as research tool. LTR students do not have fear of guessing, but their guesses are rarely designed to maximize the answer's information. One step further, they do not know how to tell whether an answer is reasonable or not. For example, they do not use heuristics such as checking limiting cases or dimensional analysis. This difficulty is related to their reluctance to guess. To overcome this natural reluctance, we must teach students heuristic methods; with practice, students will develop the courage to use them [6].

Problem is particularly emphasized in more descriptive disciplines, deprived of adequate mathematical apparatus.

1.3 Enchanted by difficult recipes

Seriousness and complexity of difficult procedures, algorithms or protocols always impress students. In order to build electronic device or synthesize some complex compound, it requires a lot of efforts and strict obedience to the rules. Students learn necessary craft and handiness this way, but it leaves no room for varying of procedures which is essential for learning through research. Science is based on diversification of procedures. Educated disobedience to the rules is one of corner stones of scientific edifice. Unreasonably complicated recipes are not suitable for students' research projects. In such cases, student simply can not see the wood for the trees.

1.4 Enchanted by shiny boxes

Another thing that regularly fascinates students is new, nicely designed instrument. It does not matter what is written in the certificate, they always believe more a shiny piece of equipment. Measuring equipment with pompous names seriously endanger students' readiness to be critical about results. The same thing stands for software. The simpler it is, you think more about how it works and use more checking points. Do not give students sophisticated piece of equipment, it would mesmerize them.

1.5 Terminological barrier

The first thing that LTR students learn is how to mimic professionals. They use scary terminology and slang of the "big science" colleagues. Students, probably, believe that using (or copying) of incomprehensive formulations and slang would contribute to the seriousness of the work. Also, we have protective effect of the terminological barrier. Students often use it to protect themselves against unpleasant questions. Unpronounceable words would keep curious characters away. The most serious problem that arises from this behavior is the lack of the feedback. Students are deprived from comments, critics, suggestions, proposals for further work, etc. The only person invited to express its opinion is the supervisor, the person who proposed or shaped the project at first place. When you enter such a *circulus vitious*, it is hard to get out.

1.6 The lack of comparisons

Students' papers often look like series of self-sufficient, moderately redundant and not particularly informative statements. There are no comparisons with other models, methods, results, conclusions or interpretations. Why is that? Comparisons are basic idea of all observations, measurement and experiments. One would expect that students make comparisons all the time because that is the easiest way to add up small pieces of information. However, it seems that students do not see what are they supposed to compare. It looks like another example of students' inability to tell apart important and trivial results. Practice of inventive and everlasting comparisons is something that we have to teach them. They should always compare their models, methods, results, conclusions, interpretations, etc. with counterparts in other papers.

1.7 Incomprehension of experimental error

Teaching of error theory and probabilistic reasoning is important part of learning through research. Students calculate errors, probably because we asked them to do so, but they do not recognize information in this entity. They do not include error estimation in process of conclusions inferring.

1.8 Usage of statistics as a black-box

Statistics also has some mesmerizing properties. It seems that statistical tests are recognized as magic wand which even provisional categories easily turns into "statistically significant" conclusions. This blind confidence that statistics will do something so we would not have to use brains at all is disastrous for learning through research. Really precious phenomena for practicing research are simple enough be explored and described in a few weeks, but hard enough so we would not be able to find "textbook explanations". Situations where straight-forward statistics fails to produce reasonable explanations are kind of problems that we are looking for.

1.9 Uninformative graphs

The way that students present their results is yet another manifestation of incomprehension of relative value and importance of numbers they obtained. Principle that "graph's greatest value is obtained when it forces us to see what we are not expecting" [7] is hard to follow if you do not expect anything. This problem is strongly intertwined with the lack of educated guesses. The other minor problem concerning graphs is rote usage of graphical software. For general purpose software all data that given in a table are equally important. Students are supposed to exclude uninformative or redundant and emphasize really important parts. Not to mention that we expect them to be creative at this age.

1.10 Personal contribution

Usage of references in students' papers is quite serious problem. Students do not distinguish what is a common place, their personal contribution or result produced by some other researcher. Of course, great deal of responsibility here goes to the supervisor. For the students alone, this problem might look marginal but resolving of these small dilemmas helps to extract what is really significant and present it adequately. Particularly important part of students' research work is to recognize fruitful ideas used in the research and to realize where did they come from. Meaningful usage of references and acknowledgements is indicator of maturity of researcher as well as a research tool.

1.11 Adopted interpretations

Research papers can not be written without interpretations of results. Students, for many reasons, feel insecure here. They do not know enough to see the broader context of the problem they investigated. As interpretation is the assignment of meaning to abstract symbols, we surely need some meta-knowledge in order to construct such an assignment. This problem is, in most of cases, too hard for students. The trivial solution is to listen to the supervisor. If you do not have a supervisor, you can simply adopt interpretations from

a popular book or review paper. Unfortunately, sticking to a single interpretation is very dangerous practice. It would be much better to write a list of possible interpretations with adequate references, but students rarely do so.

3. Conclusions

There is a segment of research process where LTR science can not be different from "real" science: strict and persistent usage of scientific method. You can't make any compromises here. Research work, of course, can be made on pretty bad model, uncompleted, with tentative results and trivial conclusions only and it still can be correct. Persistent use of scientific method gives no guarantee scientific value of obtained results. However, original scientific contribution has to be less important in LTR than learning of methodology and correctness in communication of results.

Gifted students or students extraordinary motivated for science possess a lot of skills required for scientific research and autonomous learning through research. However, such endeavor is rarely autonomous. There are always "guides" that misguide students because of the lack of time, the lack of motivation, etc. Facilitators of extracurricular science education programs should be prepared to protect students from supervisors whenever it is necessary. This misguiding is just a part of a greater problem: students can not distinguish important pieces of information from the rest of material. They certainly need a help here.

Finally, here are a few suggestions for facilitators of students' research projects:

- teach students to use educated guesses
- keep them away from unusually rigid procedures and instruments that one can not play with
- protect them from supervisor "too busy" to discuss problems with students
- ask them to find alternative, if possible non-statistical, way to discard hypotheses
- ask them to write acknowledgements
- ask them to make short list experiments that could reject applied model or inferred conclusions
- propose peer review as the procedure for accepting students' papers

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