

What are Experimental Skills? A Study with In-Service Teachers

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Abstract. Developing and fostering ‘experimental skills’ is one of the goals of Physics laboratory courses. In a pilot study reported here, the authors investigated what do teachers and lab instructors understand by the term ‘experimental skills’. Do they associate only psycho-motor skills or they include analytical, mathematical, cognitive and other skills under the title ‘experimental skills’. The authors reports the results of a study with 39 teachers from across India, who were directly involved in teaching laboratory courses at various schools and colleges for at least 8 years. Teachers were asked to describe what are ‘experimental skills’ required in experimental physics and to identify and make an exhaustive list of experimental skills which they would like their students to develop through laboratory courses from grade 8 till undergraduate level. The responses were analysed and categorised. The results indicate that teachers were not able to separate psycho-motor, cognitive and affective abilities and skills. This is essential because the tasks, methods, contents and learning processes involved in the development of these psycho-motor, cognitive and affective skills and abilities are different and should be appropriately emphasized during the designing of a laboratory course and strategy for instruction and assessment.

1. Introduction

The physics laboratory courses are supposed to develop in students, a variety of important cognitive and psycho-motor abilities and skills related to experimental physics. Several reports [1, 2, 3] indicate that developing and nurturing ‘experimental skills’ is one of the important goals of laboratory courses. During a recent survey [4] with senior school, college and university teachers on “What are the objectives and goals of laboratory courses?”, it was noted that several teachers identify development of experimental skills as a major objective and goal of laboratory courses. During this survey, it was noted that many teachers had several skills and abilities clubbed together in an unorganized manner under the title of ‘experimental skills’. Therefore it was decided to take inputs and understand what teachers really mean by experimental skills. Do they associate psycho-motor skills or they include other analytical, mathematical, cognitive skills under the title ‘experimental skills’.

2. The study

In January, 2018, we organized Active learning in Optics and Photonics - Experimental Problem Solving (ALOP-EPS) workshop for 39 high school and college teachers from across India. All the participating teachers were directly involved in teaching laboratory courses at various schools and

colleges for at least 8 years. At the end of the second day teachers were given a free response feedback form in which they were asked to a) describe what are ‘experimental skills’ required in experimental physics and b) to identify and make an exhaustive list of ‘abilities or skills’ which they would identify as experimental skills” which they would like their students to develop through laboratory courses from grade VIII till undergraduate level. We collected their written feedback forms at the end of the third day.

3. Scheme of analysis and categorization

Teachers’ responses were diverse and ambiguous indicating they were not clear on how to describe experimental skills. Further, we received 252 statements or items as part of their list of abilities or skills which they would identify as experimental skills. Several of the items were overlapping or similar. Based on these responses from teachers, several abilities and skills were combined in the following six broad categories.

- 1) Knowledge and theoretical understanding of Physics (which include, knowledge about facts, concepts, laws and principles in physics, interrelations of variables, conceptual understanding, theoretical models used in Physics, modelling an experimental situation)
- 2) Psycho-motor skills (which include the use and handling of a wide range of laboratory instruments and tools, skill of alignment, measurement, adjustment, control, judgement, drawing graphs, recording, setting up the apparatus)
- 3) Mathematical manipulations and calculations (which include mathematical manipulations, linearization of equations, numerical calculations, calculation of uncertainties, data analysis, graphical representation, statistical treatment of data, computational methods, use of software/applications and programmes for data analysis)
- 4) Information about measurements, instruments, methods and processes required in Physics (which include information about standard instruments, equipments, measuring instruments, experimental systems, sensors and data acquisition, common scientific methods, processes, techniques, used in experimental physics, scientific experimental method, details of measuring instruments (how to use, precautions, principle of operation, least count, accuracy, precision, resolution))
- 5) Cognitive and processing abilities (which include application, comparison, synthesising, analysing, interpreting, hypothesizing, predicting, observing, classifying, inferring, designing, critical thinking, decision making, procedural understanding, problem solving)
- 6) Communication and reporting of scientific work (which include scientific writing and communication, communicating data, results and conclusions of an experiment, oral presentations and reporting of scientific work)

It is noted that there is a lack of clarity on what kind of abilities and skills can be developed more effectively through lab courses. Hence there is a need to identify the above mentioned aspects clearly as separate set of abilities and skills since each of these six abilities may require different type of tasks, activities, method of instruction, strategies and approaches for effective development of these abilities or skills in students. For example, Realtime physics [5], Workshop physics [6], Physics by Inquiry [7], Active learning [8, 9], Interactive lecture demonstrations [10], More understanding with simple experiments (MUSE) [11], PhET [12], etc are best suited for introducing and fostering deeper understanding of physics. Mathematical manipulation capabilities may be developed by giving to each student, data collected by someone earlier and relevant tasks on calculations, representations, statistical treatment as home assignment.

4. Responses and results

Each item from teachers written response was categorized in the above six components of “experimental skills” and the total number of items in each category is summarized in Table 1.

Table 1. Summary of responses for six categories from 39 teachers

Categories	Total number of items	Percentage of items
1) Knowledge and theoretical understanding of Physics	31	12.3 %
2) Psycho-motor skills	38	15.1 %
3) Mathematical manipulations and calculations	62	24.6 %
4) Information about measurements, instruments, methods and processes required in Physics	55	21.8 %
5) Cognitive and processing abilities	53	21.0 %
6) Communication and reporting of scientific work	13	5.2 %
Total	252	100 %

We describe below some of the observations.

1) Knowledge and theoretical understanding of Physics

A total of 31 items (12.3 % of the 252) were listed which may be categorized under this category which include, to relate the concepts used in the given experiment, to have basic theoretical understanding required for the experiment, have firm grasp/better understanding of concepts involved, understanding of the concepts, acquire knowledge about various principles, conceptual understanding, understanding of dependence of physical variables involved, use of proper equations and theories, theoretical knowledge, understand the concepts more deeply, relate various parameters dependence on each other, understanding limitations and approximations of theory

2) Psycho-motor skills

A total of 38 items (15.1 % of the 252) were listed which may be categorized under this category which include, to set-up an experiment, make electrical connections, to record temperature, use of optical bench, segregate the equipments, adjust the range of ammeter or voltmeter, setting up of ballistic galvanometer, read value from the instruments/meters, record observations, arranging the apparatus, learn to handle the apparatus carefully and safely, hammering, nailing etc, listen the exact sound and make action, observing the lower and upper meniscus of a fluid, handling skills so that there is less wear and tear, handle apparatus wisely with all the precautions without any risks.

3) Mathematical manipulations and calculations

A total of 62 items (24.6 % of the 252) were listed which may be categorized under this category which include, mathematical calculations, computational methods for large data, graphical representations and calculations, error analysis, graphical analysis, draw graphs, slopes, line fit, to get slope/intercept, statistical analysis of data, proficiency in calculations, conversion of units like length from meter to centimeter, foot etc, identify the graphs which should be plotted to facilitate analysis, averaging quantities, using softwares and programs, mathematical skills

4) Information about measurements, instruments, methods and processes required in Physics
A total of 55 items (21.8 % of the 252) were listed which may be categorized under this category which include, identification of the apparatus and components required for the experiment, precautions to be taken, familiarity with the tools of measurement, function of each instrument, knowledge of calibration / least count, idea of all the instruments about the construction, principle and working of instrument, knowledge of least count of an instrument, knowledge of the precautions, identifying the required equipment with necessary range and least count, understand the limitations of equipment and uncertainties involved in measurements, knowing the experimental procedure clearly, identifying the steps of performing the experiment, do's and don'ts of handling a setup

5) Cognitive and processing abilities

A total of 53 items (21 % of the 252) were listed which may be categorized under this category which include, interpretation of data, ability to comprehend and articulate the concept being validated, have the ability to analyze the problems and improvise in the set up, ability to arrive at interrelations between multiple evidence, designing a new experiment, converting scientific knowledge into technology, making a hypothesis, thinking critically, troubleshooting a problem, identify where something has gone wrong during the experiment, interpretation of data and results, analysis of observations, planning the experiment, innovative modification of the given experiment, ability to critically evaluate the methodology used, coming to conclusion, designing experiment, design a working model etc.

6) Communication and reporting of scientific work

A total of 13 items (5.2 % of the 252) were listed which may be categorized under this category which include, meticulous documentation and recording skills, noting down their data, representing answer with correct significant digits, report your findings, communicate effectively, prepare systematic tables, ability to report the findings of the study in a legible, scientific language, oral presentation, reporting of results, communication skills, collaborative work habits etc.

It is interesting to note that out of 252 items which teachers would identify as experimental skills, there were 1) 62 items (24.6 %) were related to mathematical manipulations and calculations, 2) 55 items (21.8 %) were related to information about measurements, instruments, methods and processes required in Physics and 3) 53 items (21 %) were related to cognitive and processing abilities. Further, there were 31 items (12.3 %) related to knowledge and theoretical understanding of Physics. Only 38 items (15.1 %) were related to Psycho-motor skills.

5. Conclusions and Implications

The feedback indicated that teachers were not able to separate psycho-motor, cognitive and other abilities and skills. Teachers combine several abilities and skills in a very complex manner and bunch them together under the heading "experimental skills". This makes their task of teaching students and fostering these abilities and skills more difficult by combining several varieties of skills and abilities in a very complex manner. This categorization is essential because the tasks, methods, contents and learning processes involved in the development of these psycho-motor, cognitive and affective skills and abilities are different and should be appropriately emphasized during the designing of a laboratory course and strategy for instruction and assessment.

We feel that while designing lab courses and curricula we must identify specific set of abilities and skills as goals and choose experiments, activities, demonstrations and the strategies carefully to focus on the goals set out for the course. Different kinds of experimental activities should be included with a focus on development of specific set of abilities. We should use various approaches which include workshop physics, realtime physics, active learning, experimental problem solving (EPS) [3], Interactive lecture demonstrations, More understanding with simple experiments (MUSE) activities,

Investigative Science Learning Environment (ISLE) labs [13], peer instruction [14] in lab, exhibits and model making, student projects.

6. References

- [1] Goals of the Introductory Physics Laboratory, American Association of Physics Teachers 1998 *American Journal of Physics*, **66** p 483, DOI: 10.1119/1.19042
- [2] Zwickl B M, Finkelstein N, and Lewandowski H J 2013 The process of transforming an advanced lab course: Goals, curriculum, and assessments, *American Journal of Physics* **81**, p 63; DOI: 10.1119/1.4768890
- [3] Khaparde R B and Pradhan H C 2008 *Training in Experimental Physics through Problems and Demonstrations* (Mumbai: Penram International Pub. Pvt. Ltd) ISBN-13 978-81-87972-34-1
- [4] Khaparde R, What are the objectives and goals of physics laboratory courses ? A survey with college teachers, *proceedings of GIREP-ICPE-EPEC 2017, IOP Journal of Physics Conference Series (JPCS)*, 2017 (upcoming)
- [5] Sokoloff D R, Thornton R K and Laws P W 1997 *RealTime Physics: Active Learning Laboratories Module 1 and 2* (New York: Wiley).
- [6] Laws P W, Boyle R J, Cooney P J, Laws K L, Luetzelschwab J W, Sokoloff D R and Thornton R K 1997 *Workshop Physics Activity Guide* (New York: Wiley)
- [7] McDermott, L.C. and the Physics Education Group, University of Washington 1995 *Physics by Inquiry Vols. I and II*, (New York: Wiley).
- [8] Meltzer D E and Thornton R K 2012 Resource Letter ALIP-1: Active-Learning Instruction in Physics *American Journal of Physics* **80** p478; DOI: 10.1119/1.3678299
- [9] Sokoloff D R 2016 Active learning strategies for introductory light and optics *The Physics Teacher* **54** p18; DOI: 10.1119/1.4937966
- [10] Sokoloff D R and Thornton R K 1997 Using interactive lecture demonstrations to create an active learning environment *The Physics Teacher* **35** p340; DOI: 10.1119/1.2344715
- [11] https://www.eps.org/members/group_content_view.asp?group=85190&id=187784
- [12] <https://phet.colorado.edu/>
- [13] Etkina E and Heuvelen A V 2001 Investigative science learning environment: Using the processes of science and cognitive strategies to learn physics in *Proceedings of the 2001 PERC* edited by S. Franklin, J. Marx, and K. Cummings p17 (New York: Rochester)
- [14] <http://www.peerinstruction.net/>

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