Optical Surface Profilometry as a Means to Build Experimental Research Skills Including Planning

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Abstract: An optical surface profiler is used as a sophisticated, high-tech, "high"-cost instrument for learning experimental research skills in the context of a Masters in Research degree. Students are being prepared for higher degree research. © 2021 The Author(s)

1. Introduction

1.1. Motivation

One of the paradigms in research; especially multidisciplinary, team-based research; is that characterization of experimental samples is often completed by skilled professionals running a highly sophisticated instrument or facility, and the measurements are then passed to a researcher, often inexperienced, for interpretation and to progress the science. The realities of time-poor, intense working environments around such facilities may preclude the expert who completed the measurements from being actively involved in the downstream analysis. Limitations in pre-planning the measurements, by the requesters, can also limit the subsequent science that can be elucidated. There are risk factors around capturing all the required information for, and, then carrying out robust and correct analysis of results. A plenary speaker on electron microscopy (EM) at an international nanotechnology conference held in Australia many years ago made the observation, from his reviewing of the abstracts at the conference, that of order 30% of the papers involving EM had issues of concern when correlating the interpretation of the results with the settings of the instrument. Such anecdotes reinforce a clear point of principle that any scientist, including early career researchers, need to have a good understanding of the instrument before planning, using, and interpreting & analyzing results from its use. For students completing a masters of research degree leading to PhD research in photonics, we address appreciating this principle through learning about and using a high-end optical surface profiler (Bruker NT9800). The physical optics and working principles of this instrument are core content for photonics students. Several generic experimental research skills are learnt and further developed through a small research project using this instrument. The learning objectives are listed below.

Students are made aware that they should take this experience as an example of a process they will repeat as and when they are engaging with planning experiments and then interpreting and analyzing the results from use of any of the multitude of standard characterization techniques throughout their working lives.

1.2. Learning Objectives

1. Core knowledge: How an optical surface profiler (OSP) works.
2. Creativity: What is the interesting, significant, impactful and/or technology-based research question.
3. Experimental planning: How to plan an experiment using such an instrument, including scoping all the requirements so that a skilled user could complete the measurement. A risk assessment and any Work Health and Safety issues associated with the materials and techniques must be included.
4. Experimental skills: How to use the instrument.
5. Experimental record keeping: How to achieve the standard expected of a professional researcher.
6. Precision and accuracy: How to maximize these in the measurements so that the best instrument capability is achieved, and how to assess the reliability of data, and identify measurement artifacts when they arise.
7. Interpretation and analysis: Using experimental data to generate the best possible science from the study, and, to quantify errors and uncertainty.
8. Visualization of data: How to use tools such as Matlab and Python to visualize the results, and to also inspire new creative directions in investigative analysis and effective communication and presentation.
9. Written communication: How to report the experiment and analysis in a professional manner.
10. Oral presentation: How to present the experiment and analysis in a professional and engaging manner.

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Students are encouraged to reflect on how ethics and responsible conduct in research inform best practice and best outcomes from research. They are instructed to create and benefit from opportunities to collaborate which should be duly acknowledged in record keeping.

2. Implementation and Outcomes

Students are supported to achieve the learning outcomes listed through workshops, a tailored library of learning resources (subset of these [1-6]), and a series of assessment tasks. The latter have differed in different year offerings but are selected from: original experimental record keeping; experimental plan; error analysis and critical appraisal of artifacts; communication tasks (two of: a preliminary partial draft of a letter or note on your results for the scientific literature; a 10 minute scientific presentation with powerpoint slides; a 10 minute public talk with powerpoint slides; or a 250-350 word media release for a magazine or journal such as Laser Focus World or Nature News); and a take home final exam set to test understanding of the instrument and to get students to reflect on their broader learning from the activity. Students work with an expert user of the OSP to complete the experimental research plan they developed. Projects that students have completed have included optical surface profiling of the radial silks of several different species of Australian spiders, profiling adhesive droplets on spider capture silks; determining the effect of long term exposure to air on high quality, polished fused silica; evaluating the flatness or curvature of high quality mirrors; and measuring surface roughness of various surfaces including glasses.

All the students, to date, who have enrolled in this component of the Masters of Research (MRes) degree had previously completed a three year undergraduate degree (BSc major in physics or major in astronomy and astrophysics) at Macquarie University (MQU). We regard the MQU BSc program as being strong in developing experimental skills through a substantial compulsory component of experimental physics being embedded in core units of study, in all 3 years of the program. This includes high level experiments carried out over multiple weeks in the final year. Thus, we introduced this advanced experimental research skill learning activity confident that students would be well prepared for it. In general we found this to be the case on the aspects pertaining to learning new core knowledge, confidence to take part in completing the experiments, record keeping and communication. What we learned was how relatively ill-prepared the students were to take responsibility for planning an experimental study. The students required intense support to engage with this process and their reflections on their learning spoke strongly of the lack of confidence they had to engage with deciding on a research question or hypothesis and independently planning to answer or test it.

We designed this activity to support student learning of the need to understand a sophisticated instrument in order to appropriately interpret and analyse results that come from its use. The design is fit for purpose in achieving this and we can recommend this, or a close analogue, to others for inclusion in masters programs, for this purpose. But, what we further learned was that our undergraduate experimental laboratory program appears to be under-preparing students to engage with creative research and its planning. Thus, we recommended review of the experimental learning in the BSc degree to incorporate more experiences where students plan, develop, execute and analyze an experiment, at a level appropriate to the year, rather than executing and analyzing experiments without the planning stages.

3. References

[1] Wyko NT9800/9300 profiler: Setup and Operation Guide, Veeco Instruments Inc. ©2007. (Note Veeco is now Bruker).

[2] Patricia Gosling and Bart Noordam, "Designing Good Experiments", ch.5 in *Mastering Your PhD* (Springer-Verlag 2006, 2011).

[3] Suggestions for Keeping Laboratory Notebooks, https://otl.stanford.edu/suggestions-keeping-laboratory-notebooks (accessed 31 May 2021).

[4] Guidelines for Keeping a Laboratory Record, https://www.ruf.rice.edu/~bioslabs/tools/notebook/notebook.html (accessed 31 May 2021).

[5] Les Kirkup, *Experimental Methods for Science and Engineering Students: An Introduction to the Analysis and Presentation of Data 2nd Ed*. (Cambridge University Press, 2019).

[6] L. Kirkup and R B Frenkel, *An Introduction to Uncertainty in Measurement: Using the GUM (Guide to the Expression of Uncertainty in Measurement)* (Cambridge University Press, 2006).