institute of Chalmers University of Technology in Gothenburg as well as the Swedish National Facility for Radio Astronomy). Future systems will soon be operating at the Institute of Astronomy at Lund University, the Department of Physics at the Royal Institute of Technology in Stockholm, the Institute of Astronomy at Uppsala University, and finally, a second system at OSO. It is hoped that many future astronomy and physics undergraduate students will be stimulated by using these radio telescope systems for their own personal interaction with the wonders of the sky.

THE CCD IN UNDERGRADUATE PRACTICAL ASTRONOMY

D. McNally
University of London Observatory, Mill Hill Park, London NW7 2QS, UK

1. Introduction. The CCD is producing a revolution in astronomy at the end of the 20th century, equivalent to the photographic revolution at the end of the 19th century. That revolution spread from the major international observatory right through the university observatory to amateur astronomy. Small telescopes, previously considered too small or too poorly situated for worthwhile work are now empowered in a way that was undreamt of surprisingly few years ago. With exposure times in seconds and minutes where previously they were in hours, it means that those of us who do not enjoy the best of climates (or weather) can now utilise fleeting half hours of clearish skies. The response of CCDs also means that for those of us who "enjoy" superb bright skies at night, imaging of extended objects is possible once again. It is not surprising that CCDs have been introduced into the undergraduate astronomy practical class.

2. CCDs at the University of London Observatory. I had wished to introduce CCD detectors at the University of London Observatory from about 1985. Apart from natural reluctance of colleagues to abandon the classic astronomical plate, there were two reasons why our entry into this field was delayed - cost and the opinion that undergraduates and cryogenic fluids did not mix. Declining costs and the development of Peltier cooled CCD detectors removed those two obstacles.

The problem to be faced was what criteria should be applied to selecting a CCD for undergraduate use. Very clearly professional quality CCDs were still beyond our financial grasp, yet if students were to be introduced to CCD based working, the system could not be a toy. A survey of the market in 1989-90 revealed that a local firm (Wright Instruments Ltd., Enfield) was offering a 600 x 400 pixel detector, Peltier cooled to 70°K below ambient. The price was not cheap but with software and dedicated PC the bill was of the order of £20,000. We went ahead and mounted the system for the Observatory's spectral classification spectrograph designed by M.M. Dworetsky. The CCD camera may also be used for imaging. It was at once clear that we had a winning combination.

A second large format (1200 x 800 pixel) CCD was obtained from the same

company at a cost of the order of £30,000 in 1993 and a Santa Barbara instrument Group ST4, and ST6 were obtained for two new 10" Meade telescopes. The photographic plate was on its way out for many teaching applications.

3. Logistics. Given the advantages of the CCD - short exposures, linear response, digital recording, ease of data reduction - certain other essential purchases were necessary. A VAX Station 3100 was obtained and its disc storage capacity had to be increased to 1 Gbyte in order to cope with the data reduction and handling of CCD images. Each CCD has its own dedicated control PC but the reduced image is transferred to the VAX Station for analysis. We were fortunate in being supplied with data analysis packages (e.g. FIGARO and DIPSO) by the UK STARLINK facility. This means that undergraduates are able to use professional packages but do not make any demand on the facilities of STARLINK itself. Any expense on CCD detectors has to be matched for the appropriate data reduction and analysis facilities.

One then has to consider how to integrate CCDs into the teaching programme. This is not simply a matter of replacing photographic plates by CCDs. Were we starting from scratch we would of course start with the first year. However, the current small, cheap CCDs were not then available and we started with the 3rd (final B.Sc.) year. We have a training programme on CCDs as part of the 3rd year astronomy practical - sources of detector noise, flat fielding, removal of cosmic rays and radioactive decays (from potassium in lenses), background subtraction. The CCDs are used for imaging on the Radcliffe 24"/18" refractor and for recording spectra on the Allen 24" reflector and are integrated into previously existing experiments. In 1994/95 we shall begin again to see if suitable relative photometry is possible at the ULO site using the large format CCD on the Radcliffe refractor.

With the advent of the ST4 and ST6 we can introduce 1st year students to CCD detectors. Again they receive some basic training in the use of CCDs before moving on to imaging. The ease with which a range of objects can be imaged is very encouraging to 1st year students who, with a little application, can build a portfolio of interesting objects. They can produce hard copy images using a Mitsubishi video copy printer. They learn a great deal about observational technique and procedure in the process.

We are now moving to a situation where we can clarify the CCD learning process. The first year programme remains as an introduction to the CCD in astronomical observation. The physics of the CCD is being moved to the second year - a CCD system will be fully explored in the laboratory so that students in the third year will not need to be taught basic CCD practice so releasing time for more astrophysically based observations. Instruction in the use of reduction and analysis packages will still remain for the 3rd year.

4. Problems. There are a number of problems to be encountered with CCDs - I will not dwell on the technical but on the teaching problems. A major teaching problem is the number of software packages a student has to master; another is that the student has also to acquire a new way of looking at image data. To take the last problem first, the student has to learn to see an image as a collection of pixels. By and large photographs are not seen as a collection of grains or clusters of grains of silver. Noise and resolution are starkly there in the CCD image in a way they were not in

photography - at least to the undergraduate. It is a pedagogic value of the CCD that noise and resolution are so visible but it demands a greatly revised set of concepts on the part of the student. Some find this revision a very challenging task. The second problem of mastery of packages is one of the magnitude of the flood of new procedures to be learnt. There is a tendency for a sophisticated package to overwhelm by its sheer range of options. We have found that very basic "crib" sheets to allow students to get started and to see their way to a scientific result were essential. Most students rapidly outgrow such "cribs" and begin to revel in the facilities of the STARLINK package. A few students have computer aversion and do not progress beyond the crib sheet level of mastery.

The CCD has not made life easier for the student. It is true that they have more chance of recording an image; it is true that more students per hour can use the telescope. But there is a price to be paid for this in terms of intellectual demand on the student. It is a good discipline to think of images in digital terms but it is not as yet an easy discipline. There is the flood of computer packages to be mastered. We hope that by meeting the CCD in the 1st and 2nd years at university, students will develop an understanding of, and familiarity with, the CCD. Then in their final years they may learn to use the CCD with increasing confidence and effectiveness.

5. Conclusion. The CCD is here to stay in the teaching situation. It is of great advantage in improving access to the sky in scheduled classes. It allows students to accumulate a range of images for analysis. The CCD is not cheap either to purchase or maintain and components will require replacement on a 5 to 7 year cycle. Their introduction will make practical classes more, not less, expensive to mount. But if students in their professional life are to get the most from CCD detectors, they must begin their acquaintance as undergraduates and participate in the freedom, and in the disciplines, that the CCD brings.