Monitoring practical science in schools and colleges

Main report

Durham University

Prepared for the Gatsby Charitable Foundation and the Wellcome Trust

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Disclaimer

The views and opinions expressed in this report are those of the authors and do not necessarily state or reflect those of the Gatsby Charitable Foundation, Wellcome Trust or Nuffield Foundation.

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3 Foreword

The Gatsby Charitable Foundation and Wellcome firmly believe that hands-on, practical experiences should be an integral part of a young person's science education. Practical work supports the learning of scientific concepts and processes, and develops the technical and higher level skills required for a broad range of careers. Practical activities can also be highly motivating and increase engagement with scientific study. However, recent changes to qualifications coupled with budget pressures have heightened concern that practical science in schools is under threat.

This research was commissioned at a time when Ofqual and awarding organisations, among others, hoped new science GCSEs and A levels would increase the amount and variety of practical science occurring. But some, including Wellcome and Gatsby, were concerned that the changes might lead to a de-prioritisation of practical science in schools. So, between 2014 and 2018, we funded researchers at Durham University to monitor the amount and nature of practical science in schools across England and Scotland, and to ask university staff and students about the extent to which undergraduates are adequately prepared for practical science at university.

The research found little evidence of systemic change in the amount of practical work occurring in school science lessons. While some teachers were tackling practical work previously considered too difficult or too time-consuming, it was disappointing that few were undertaking a broader range of activity, particularly extended project work. Open-ended investigations provide an excellent opportunity to develop knowledge, skills and behaviours particularly important for A level students wanting to continue into higher education.

While inconclusive, the data also suggest that university staff tend to have relatively low expectations of the practical skills of incoming undergraduates, even when they have an otherwise high bar to entry. This may be due to the range of prior qualifications they have to accommodate from a diverse, international intake.

It is always challenging to generalise from this type of research; for example, we know the teachers in our sample are more likely to be specialists in their subject than the wider workforce. But the team at Durham University have produced a hugely comprehensive and useful body of knowledge about school practical science which can be used as a baseline to monitor future change.

The report also raises some issues that warrant further exploration:

- in England, the content of GCSE science has increased markedly with many schools starting to teach key stage 4 in year 9, contracting key stage 3 to much less than three years in many schools
- the wide budget range reported for science in schools and the resource gap between state and independent schools
- the availability of laboratories able to accommodate full classes and the extent to which they are accessible to SEND students
- a possible early sighting of reduced technical support.

Further, while we welcome reform to the assessment of practical skills which has a positive impact on classroom practice, we remain convinced that students' ability to do hands-on practical science should be reflected in their final grades and that assessments must enable this.

We are grateful for the commitment and hard work of Durham University, the many teachers, technicians, staff and students who have participated in surveys, focus groups and interviews, and to the Nuffield Foundation and our stakeholder group for their support.

Ginny Page, Gatsby Foundation

Mat Hickman, Wellcome Trust

4 Executive Summary

4.1 Overview

This report presents data relating to practical work in science provision in schools[1] collected over three years in England and Scotland from 2015 - 2017. This study adopts the SCORE (2013) definition of practical work, namely:

> "A learning activity in which students observe, investigate and develop an understanding of the world around them, through direct, hands-on, experience of phenomena or manipulating real objects and materials." (p 3)

We report on the quantity and breadth of practical work undertaken and how this changed during the study. The discussion identifies possible reasons for observed outcomes. We examine how these data illustrate how school-based practical work in science prepares students for laboratory based courses at university.

Over three years, respondents comprised 4,176 science teachers, heads of science, science technicians, first year science undergraduate students and university staff responsible for first year science laboratory-based courses. Analysis of the heads of science and science teachers responding to the survey showed that they are more highly qualified than the overall teaching workforce, so results should be read with this in mind. Data were collected in year 1 of the study in 2015, during reforms to the Scottish National 5 and Higher qualifications and prior to implementation of reformed GCSE and A level science specifications in England. Data were collected in year 3 of the study (in 2017) post implementation of reforms in Scotland. In England this was at the point when A level students were completing the reformed qualifications for the first time then progressing to undergraduate study, and GCSE students had completed one year of their reformed programmes.

4.2 Key findings

1. No statistically significant universal changes (i.e. across all subjects/age ranges/school types) were found in the quantity and breadth of practical work, facilities, budget or equipment during the period of the study (2015 – 2017) in schools in England and Scotland. Changes for individual subjects, age ranges or school type were observed in some areas. However, these should be considered in context.

2. Using data from year 3 of the study as an example, the average number of hours per week of science lesson time spent on practical work was:
    a. 11 – 14 year old students in English state schools: 1.0 hour per week
    b. 14 – 16 year old students in English state schools: 0.9 hours per week
    c. Post – 16 year old students in English state schools: 1.3 hours per week

    d. 11 – 14 year old students in English independent schools: 0.7 hours per week
    e. 14 – 16 year old students in English independent schools: 0.7 hours per week
    f. Post – 16 year old students in English independent schools: 1.5 hours per week

    g. 11 – 14 year old students in Scottish state schools: 1.2 hours per week
    h. 14 – 16 year old students in Scottish state schools: 1.1 hours per week
    i. Post – 16 year old students in Scottish state schools: 1.1 hours per week

[1] Note: For brevity the term "schools" refers to schools and colleges.

A statistically significant decrease in the proportion of science lesson time spent on practical work was found between the 11 – 14 and post – 16 age ranges in both state and independent schools in England and in state schools in Scotland.

3. Students studying biology, chemistry and physics in the 11 – 14 age range carried out between 16 and 26 practical work activities per academic year. Students studying science (as a subject) carried out between 27 and 38 practical work activities per academic year. Students in the 14 – 16 age range carry out between 15 and 24 practical work activities in an academic year. Students in the post – 16 age range carried out between 18 and 30 practical work activities per academic year. The number of practical work activities that teachers reported their post – 16 chemistry students undertook within an academic year showed a statistically significant decrease for both state and independent schools in England over the course of the study. A statistically significant increase was observed over the course of the study in the number of practical work activities undertaken by 14 – 16 year old biology students from state schools in England.

4. The breadth of practical work undertaken was limited in England and Scotland. Most experiments carried out by a majority of students of all ages in all types of school required "following prepared instructions". Few opportunities were provided for students to undertake open-ended and/or long-term experiments, that is, those that extend beyond the duration of one science lesson. Long-term, extended practical work was limited to specific student sub-sets. In the post – 16 age range, this opportunity was provided by about 85% of English state school respondents for physics and 70% of Scottish state school respondents (all subjects combined). Lower values were observed in the 11 – 14 and 14 – 16 age ranges, as about 15 – 20% of English state school respondents, 20 – 40% of Scottish school respondents and 5 – 18% of English independent school respondents offered long-term practical work for these age groups.

5. The number of Full Time Equivalent (FTE) technicians employed by schools varied between school types. An average of 0.23 – 0.26 FTE technicians per 100 pupils were employed in English state schools; 0.48 – 0.53 FTE technicians per 100 pupils in independent schools in England; and 0.16 – 0.19 FTE technicians per 100 pupils in state schools in Scotland. There was no statistically significant change in the average number of FTE technicians per 100 pupils during the study for any school type. The difference between the number of FTE technicians between English state and independent schools in each year of the study was statistically significant. The smaller sample size in Scotland means that there was no statistically significant difference between the number of FTE technicians in English and Scottish state schools. State school science technicians tended to be generalists in both England and Scotland, supporting all science subjects. Independent school science technicians tended to be specialists, supporting one science.

6. Year 3 data showed the ratio of students per laboratory to be about 200:1 in English state schools and about 100:1 in English independent schools and state schools in Scotland. The difference between English state and independent schools was statistically significant. Between English and Scottish state schools the difference was not statistically significant due to the small sample size in Scotland.

7. Laboratories were equipped with basic equipment for whole class experiments in physics, chemistry and biology in England and Scotland. Most laboratories had gas, water, electricity, electronic white boards and projectors and facilities for teacher demonstrations. Some

laboratories lacked some equipment needed to carry out post – 16 science experiments in chemistry and biology. In year 3 of the study, 79% of respondents from state schools in England and 71% from independent schools in England and state schools in Scotland reported most or all of their laboratories were accessible to Special Educational Needs and Disability (SEND) students.

8. Heads of science reported that, on average in English state schools, funds available per student to spend on science amounted to about £11 per academic year. In English independent schools, this figure was about £34. In Scottish state schools, the figure was about £4. No statistically significant changes in budgets were observed from 2015 - 2017. The difference between English state and English independent schools was statistically significant. That between English and Scottish state schools was not, due to the small sample size in Scotland. Heads of science in English state schools were typically "neither satisfied nor dissatisfied" with their budgets. Their counterparts in English independent schools were typically "satisfied". The sample size was too small to report for Scotland. In years 2 and 3 of the study, when asked to report on whether their budget had changed since the previous year, half of respondents from state schools in England reported that their budget had decreased since the previous year. In independent schools an equal percentage of respondents reported an increase as a decrease in year 2 of the study. No respondents from Scottish state schools reported an increase in either years 2 or 3 of the study.

9. Higher Education staff had limited expectations of first year undergraduate students' practical work skills. Undergraduates were expected to be able to operate safely in a laboratory; follow and understand instructions; use mathematical concepts and skills; and take notes. However, year 3 data suggested that, for biological sciences and physics, HE staff expected first year students to understand the theory behind scientific methods encountered within practical work and to solve problems within practical work independently. School science teachers had limited awareness of university practical work and based their knowledge on their own prior experiences as undergraduates.

5 Research Digest

5.1 Background

5.1.1 Changes to science qualifications

Revised science GCSE and A level examination specifications with significant changes to practical work assessment were taught in England from September 2015 and September 2016 respectively, with completion in 2017 and 2018. In Scotland, National 5 examinations took place for the first time in 2014. Reformed Higher and Advanced Higher examinations took place in 2015 and 2016 respectively.

Previously, A level specifications (typically taught to students aged 16 – 19 years old) assessed practical work via a controlled practical activity (or activities) worth 20% of available marks for the whole programme. Of the 20%, about 10% (i.e. 2% of the total marks) were allocated to direct observation of practical work, while most were awarded for students' written accounts of controlled practical work activity (Ofqual, 2017). Practical work was teacher-assessed, and moderated by examination boards. Overall, course content was organised in a modular format, permitting students to re-take single modules to enhance their overall grades. After one year, modules completed comprised an "Advanced Supplementary" (AS) qualification that students could "top up" with a further year of study, known as "A2", to complete a full A level. Revised A level specifications adopt a linear structure which is formally examined at the end of the two-year course. From 2015, AS qualifications became separate, stand-alone qualifications. A level practical work assessment changed to comprise two components (Ofqual, 2017): a written assessment intended to indirectly assess practical skills (15% of marks); and a 'practical endorsement' confirming students have demonstrated competence in skills common to all sciences developed through opportunities for regular hands-on practical work. Students must complete a minimum of 12 practical activities across the two years of an A level course. Students receive a pass or an unclassified grade for the endorsement, which is reported alongside, but does not count towards their final A level grade. The endorsement is teacher-assessed against specified criteria for practical science assessment (Ofqual, 2016 pp 15 - 16). Examination boards employ monitors to ensure endorsement records are kept.

The new GCSE specifications (typically taught to 14 – 16 year olds) require students to complete a minimum of eight hands-on experiments. No formal endorsement is provided but records must be kept of practical work completed. In addition, 15% of marks in written examinations are intended to assess knowledge of practical work. The Department for Education reported that approximately one third of schools may commence teaching GCSE in year 9 (age 13 – 14), a year earlier than is traditionally expected (Department for Education, 2018). This is a lower value than reported in this study (see section 6.1.2).

In Scotland, National 5 examinations and reforms to Higher and Advanced Higher qualifications were introduced from 2013 onwards. Assessment of practical work in National 5 and Higher qualifications is through an assignment and at Advanced Higher level through a project-report, conducted over a period of time. National 5 examinations took place for the first time in 2014. Reformed Higher and Advanced Higher examinations took place in 2015 and 2016 respectively.

At the time publication, changes arising from implementation of new GCSE and A level specifications in England are ongoing. Findings presented in this report represent the situation within schools responding to the study before and during the period of change. Further work is required to obtain information about the situation relating to practical work post-change.

5.1.2 Research Methods

Five data collection instruments were used:

1. The "school staff survey": a survey administered electronically and on paper of heads of science, science teachers and science technicians in schools[2] in England and Scotland (survey text available in Appendix 4).
2. The "school focus groups and telephone interviews": Focus groups in England and telephone interviews in Scotland with heads of science, science teachers and science technicians in schools (focus group and interview schedules available in Appendix 5)
3. The "HE staff survey": an electronically administered survey of Higher Education (HE) staff in England and Scotland involved with the teaching of first year undergraduate laboratory courses (survey text available in Appendix 6).
4. The "HE student survey": an electronically and paper administered survey of first year undergraduate students in England and Scotland who took a laboratory class as part of their course (survey text available in Appendix 7).
5. The "HE telephone interviews": Telephone interviews with HE staff in England and Scotland involved with teaching first year undergraduate laboratory courses (interview schedule available in Appendix 8).

5.1.3 Samples

The School Staff Survey

More than 2000 respondents from schools across England and Scotland completed the school staff survey over three years. The survey was administered electronically to schools in England and Scotland and was open to receive responses during Spring and Summer terms in 2015 (year 1 of the study), 2016 (year 2) and 2017 (year 3). The timescale for implementation of changes to technical facilities led to science technicians being surveyed in years 1 (2015) and 3 (2017) but not year 2 (2016) of the study. As the surveys were completed anonymously, we cannot confirm if the same participants responded each year. Wide variance in responses from staff within the same school within the same year of the study was observed. Thus responses are drawn from a pooled cross-sectional sample with all responses from staff within a school in each year of the survey being used in the analysis. Responses from staff are treated independently and analysed as individuals. Table i shows the numbers of schools responding to the school staff survey.

Table i. Schools responding to the school staff survey by school type and nation in each of the three years of the study. Schools are unique within each survey year. Science technicians were only surveyed in Year 1 and Year 3 of the study.

Nation	School type	Year 1	Year 2	Year 3	Total
England	State schools	425	212	912	**1549**
	Independent schools	163	121	218	**502**
Total		**588**	**333**	**1130**	**2051**
Scotland	State schools	34	44	69	**147**
Total		**34**	**44**	**69**	**118**
Grand total		**622**	**377**	**1199**	**2198**

Respondents' occupations are shown in Table ii. Analysis of respondents' qualifications shows our sample is more highly qualified than the overall teaching workforce (Gov.uk, 2018). Results should be read with this in mind.

[2] Note: Note: For brevity the term "schools" is used to refer to both schools and colleges throughout the study.

Table ii. Individuals responding to the school staff survey by occupation. Science technicians were only surveyed in Year 1 and Year 3 of the study.

Occupation	Year 1	Year 2	Year 3	Total
Technician	274	None	1224	**1498**
Science teacher	214	347	584	**1145**
Head of science	268	235	262	**765**
Total	**756**	**582**	**2070**	**3408**

The School Focus Groups and Telephone Interviews

The numbers of schools participating in focus groups and telephone interviews are shown in Table iii. Eighteen schools participated in focus groups and telephone interviews in all three years of the study.

Table iii. Schools participating in the focus groups and telephone interviews by nation.

Region	Year 1	Year 2	Year 3
England			
State schools	15	16	18
Independent schools	6	5	6
Total	**21**	**21**	**24**
Scotland	3	8	11
Total	**24**	**29**	**35**

The HE Staff and Student Surveys

Data were collected from staff teaching laboratory courses to first year undergraduate students in biological sciences, chemistry and physics departments via an anonymous survey administered electronically in the autumn terms (October – December) of 2015, 2016 and 2017. We cannot confirm if the same staff members responded each year. A cross-sectional sample including responses from all institutions in each year is used for analysis. The numbers of respondents to the HE staff survey are shown in Table iv. The column "more than 1 subject" indicates staff who were teaching across more than one department (e.g. teaching both biological sciences and chemistry).

Table iv. Respondents to the Higher Education staff survey broken down by the departments in which they stated that they taught, by survey year and by nation.

Nation	Year	Biological Sciences	Chemistry	Physics	Teaching more than 1 subject
England	Year 1	14	11	13	1
	Year 2	21	21	15	2
	Year 3	19	12	12	1
Total		**54**	**44**	**40**	**4**
Scotland	Year 1	1	3	0	0
	Year 2	2	5	2	0
	Year 3	5	4	2	0
Total		**8**	**12**	**4**	**0**
Grand Total		**62**	**56**	**44**	**4**

Students undertaking a laboratory course as part of their biological science, chemistry or physics first year undergraduate course were invited to participate in an online anonymous survey. Respondents were drawn from a small number of institutions annually (Table v). Findings for HE students are presented narratively in the report due to the low number of respondents and institutions.

Table v. Number of students responding to the HE student survey. The number of departments is indicated in brackets. Respondents were students who remained in the sample for analysis after exclusions.

Survey year	Biological Sciences	Chemistry	Physics	Total
Year 1	26 (2)	22 (1)	69 (5)	117 (7)
Year 2	143 (12)	78 (9)	91 (7)	312 (16)
Year 3	50 (4)	46 (6)	50 (5)	146 (12)
Total	**219 (14)**	**146 (12)**	**210 (9)**	**575 (21)**

The HE Telephone Interviews
The numbers of Higher Education staff participating in telephone interviews are shown in Table vi. Six interviewees participated in the interviews in all three years of the study.

Table vi. Institutions participating in the telephone interviews split by department and nation. B – Biological sciences, C – Chemistry, P – Physics.

	Year 1				Year 2				Year 3			
Nation	**B**	**C**	**P**	**Total**	**B**	**C**	**P**	**Total**	**B**	**C**	**P**	**Total**
England	3	5	5	**13**	3	6	5	14	4	5	3	**12**
Scotland	1	0	0	**1**	2	3	1	6	2	2	1	**5**
Wales	0	0	0	**0**	1	0	1	2	0	2	1	**3**
Total	**4**	**5**	**5**	**14**	**6**	**9**	**7**	**22**	**6**	**9**	**5**	**20**

5.2 Findings

5.2.1 Research Question - What science practical work is provided within schools in terms of the quantity and breadth undertaken and how has this changed over the lifetime of the study?

1. Table vii shows the amount of time spent in science lessons (in hours) and the lesson time spent on practical work (in hours) in year 3 of the study. Similar values were observed in years 1 and 2 of the study. Science lesson time and the number of hours spent on practical work in science lesson time showed a statistically significant increase between the 11 – 14 and post – 16 age ranges and the 14 – 16 and post – 16 age ranges in both English state and independent schools. There was no statistically significant difference between the 11 – 14 and 14 – 16 age ranges.

Table vii. Average science lesson time (hours per week) and lesson time spent on practical work (hours per week). Respondents were heads of science and science teachers responding to the school survey questions "How much timetabled time (in hours) is allocated to the selected 11 – 14/14 – 16/Post-16 subject and qualification each week?" and "Of the allocated hours, please estimate how many hours are used on the following activities in an average week in the current year". 95% confidence intervals are shown in brackets.

Age range	England state schools	England independent schools	Scotland state schools
Science lesson time, Hours per week			
11 – 14	3.0 (2.9, 3.1)	1.7 (1.6, 1.8)	2.7 (2.6, 2.9)
14 – 16	3.2 (3.1, 3.3)	2.5 (2.4, 2.5)	3.9 (3.7, 4.0)
Post – 16	5.0 (4.9, 5.1)	5.1 (5.0, 5.3)	4.6 (4.4, 4.7)
Science lesson time spent on practical work, Hours per week			
11 – 14	1.0 (0.9, 1.0)	0.7 (0.7, 0.8)	1.2 (1.0, 1.3)
14 – 16	0.9 (0.8, 0.9)	0.7 (0.7, 0.8)	1.1 (1.0, 1.2)
Post – 16	1.3 (1.3, 1.4)	1.5 (1.5, 1.6)	1.1 (1.0, 1.2)

2. In English state schools, the proportion of science lesson time spent on practical work showed a statistically significant decrease from 32.9% in the 11 – 14 age range to 26.5% in the post – 16 age range (Table viii). In English independent schools a statistically significant decrease from 40.1% to 30.1% was seen as age range increased. In Scotland, a statistically significant decrease from 41.1% to 24.8% was found. In English independent schools, greater variation was observed for the 11 – 14 age range in the proportion of science lesson time spent on practical work compared to state schools. Independent school students in all age ranges spent a slightly higher (statistically significant) proportion of science lesson time on practical work than their state school counterparts. There were no patterns that applied consistently to all science subjects, suggesting that overall, a similar proportion of lesson time in biology, chemistry and physics was devoted to practical work.

Table viii. Proportion of science lesson time per week spent on practical work in year 3 of the study. Values are calculated from responses from heads of science and science teachers to the school survey questions "How much timetabled time (in hours) is allocated to the selected 11 – 14/14 – 16/Post-16 subject and qualification each week?" and "Of the allocated hours, please estimate how many hours are used on the following activities in an average week in the current year". 95% confidence intervals are shown in brackets.

Age range	England state schools	England independent schools	Scotland state schools
11 – 14	32.9 (31.5, 34.3)	40.1 (37.7, 42.5)	41.1 (37.6, 44.7)
14 – 16	27.3 (26.3, 28.3)	30.4 (29.2, 31.6)	27.9 (24.8, 31.0)
Post – 16	26.5 (25.6, 27.4)	30.1 (28.9, 31.3)	24.8 (21.7, 27.9)

3. Students studying biology, chemistry and physics in the 11 – 14 age range carried out between 16 and 26 practical work activities per academic year. Students studying science (as a subject) carried out between 27 and 38 practical work activities per academic year. Students in the 14 – 16 age range carried out between 15 and 24 practical work activities in an academic year. Students in the post – 16 age range carried out between 18 and 30 practical work activities

per academic year. The number of practical work activities teachers reported their post – 16 chemistry students undertook within an academic year showed a statistically significant decrease in both state and independent schools in England over the course of the study. A statistically significant increase was observed over the course of the study in the number of practical work activities undertaken by 14 – 16 year old biology students from state schools in England.

4. Although no systematic (e.g. across all subjects within an age group) changes were observed over the period of the study, some statistically significant changes were observed for specific subjects, age groups and school types within the sample in the three years of data collection. These are shown in Table ix.

Table ix. Statistically significant changes over the three years of the study in average science lesson time per week (in hours), lesson time spent on practical work per week (in hours) and proportion of science lesson time per week spent on practical work. Arrows indicate whether the change was a significant increase or decrease.

Age range	School type	Change in quantity of practical work significant at P<0.05
Science lesson time, Hours per week		
11 – 14	England independent	↓Chemistry
	England state	↑ Physics
Science lesson time spent on practical work, Hours per week		
14 – 16	England state	↑Biology
Proportion of science lesson time spent on practical work per week, %		
11 – 14	England independent	↑Chemistry
	England independent	↑Physics
	England state	↑Science
14 – 16	England state	↑Biology
Post – 16	England independent	↓Biology
Number of practical work activities carried out by students during an academic year		
14 – 16	England state	↑Biology
Post – 16	England state	↓Chemistry
Post – 16	England independent	↓Chemistry

5. Science teachers participating in the qualitative focus groups in England commented that the level of content within the GCSE and A level syllabuses led to significant pressure on time within science lessons to fit in the required content. Some noted that time for practical work was limited to allow taught content to be covered in sufficient detail.

6. The breadth of practical work undertaken in all schools in England and Scotland at all ages showed a consistent pattern. Most activities required students to follow pre-prepared instructions and to analyse data. Few experiments were open-ended, that is, required students to design their own investigation using a range of equipment. No systematic changes over the course of the study were observed in tasks staff reported students undertook in practical work activities (e.g. for all subjects within an age range). Very few experiments extended beyond the timescale allowed by individual lessons. Opportunities to carry out long-term, extended practical work seem limited to specific student sub-sets. In the post – 16 age range, this opportunity was provided by about 85% of English state school respondents for physics and 70% of Scottish state school respondents (all subjects combined). Lower values

were observed in the 11 – 14 and 14 – 16 age range. Data showed that about 15 – 20% of English state school respondents, 20 – 40% of Scottish school respondents and 5 – 18% of English independent school respondents offered long-term practical work for these age groups. This suggests that students are usually undertaking the same tasks within their practical work.

7. We investigated if the proportion of practical work time correlates with the Income Deprivation Affecting Children Index (IDACI) scores for state schools in England. In year 1 of the study, a negative correlation was observed for 11 – 14 and 14 – 16 year old students in English state schools. This suggests that where deprivation is high, students experienced a lower proportion of science lesson time on practical work. This finding concurs with Wellcome Trust Science Education Tracker data (Wellcome, 2017). This correlation was not apparent in data collected in years 2 and 3 of the study. No significant correlations were found in any year with the proportion of students receiving Free School Meals (FSM).

5.2.2 Research Question - What are the main insights into any influences on the quantity and breadth of science practical work undertaken in schools?

8. Although no statistically significant systematic changes in the quantity and breadth of practical work were observed over the course of the study, factors that may influence practical work were investigated by examining teacher qualifications, the amount and nature of technician support, facilities for science, equipment, budget available to support science and examination specifications. Heads of science and science teachers were asked to report their highest qualification in their specialist science subject. Our sample was more highly qualified than the overall teaching workforce so results should be read with this in mind. No overall systematic association was found between teacher qualifications and the types of activities carried out in science lessons in years 2 and 3 of the study.

9. The number of technicians employed by schools varied by school type. English state schools employed an average of 0.23 – 0.26 Full Time Equivalent (FTE) technicians per 100 pupils across the three years of the study (Table x). The value was statistically significantly higher in English independent schools, which employed between 0.48 – 0.53 FTE technicians per 100 pupils. The value was 0.16 – 0.19 FTE technicians per 100 pupils in Scottish state schools. There was no statistically significant change in the average number of technicians per 100 pupils over the course of the study for any school type. The difference between the number of FTE technicians per 100 pupils between English state and independent schools in each year of the study was statistically significant. The difference between the number of FTE technicians per 100 pupils in English state schools and Scottish state schools was only statistically significant in year 3 of the study due to the small sample size in Scotland.

Table x. (England and Scotland) Mean number of FTE technicians per 100 pupils within schools over the three years of the study. Respondents were heads of science.

School type	Mean no. of technicians per 100 pupils		
	Year 1	Year 2	Year 3
England state	0.24 (0.22, 0.26)	0.26 (0.23, 0.29)	0.23 (0.21, 0.25)
England independent	0.53 (0.47, 0.58)	0.48 (0.44, 0.53)	0.52 (0.46, 0.59)
Scotland	0.18 (0.14, 0.22)	0.19 (0.15, 0.23)	0.16 (0.13, 0.18)

10. Table xi shows year 3 data reported by heads of science about changes in the number of FTE technicians that had occurred in their schools in the previous year. These show that a majority reported no change. However, 26% of English and 24% of Scottish state schools and 10% of English independent schools reported a decrease in the number of technicians. Three percent of English state schools and 9% of independent schools reported an increase. No schools in Scotland reported an increase. These data need to be considered alongside Table x, which shows the average numbers of FTE technicians per 100 students.

Table xi. Heads of science reporting on whether the number of FTE technicians has changed within the school in the last year.

	England state		England independent		Scotland	
Change	**Number**	**%**	**Number**	**%**	**Number**	**%**
Increased	4	3	6	9	0	0
Decreased	40	26	7	10	5	24
Stayed the same	112	72	58	81	16	76

11. Data relating to the nature of technicians' roles, that is, as "specialists" responsible for one subject only or "generalist" responsible for all sciences are presented in Table xii. These show a contrast between English and Scottish state and English independent schools. Independent schools employed most technicians as specialists in their subjects. Most state schools employed technicians as generalists supporting all sciences. A higher proportion of Scottish state school than English state school technicians were generalists. Sample sizes were too small to report for year 1 of the study in Scotland.

Table xii. Nature of science technicians' roles i.e. general or specialist science technicians. Respondents were science technicians.

Technician role	Year 1		Year 3	
England state schools	**n**	**%**	**n**	**%**
General	144	68	604	66
Specialist	67	32	314	34
Total	**211**		**918**	
England independent schools				
General	12	30	62	26
Specialist	27	70	177	74
Total	**39**		**239**	
Scotland state schools				
General	-	-	49	89
Specialist	-	-	6	11
Total	**-**		**55**	

12. Technicians worked from "preparation" rooms which store equipment and provide facilities and space for getting this ready for individual lessons. Data collected from technicians showed that the type of preparation room matched their roles (Table xiii). Hence, in English and Scottish state schools, most preparation rooms were general, so were used to prepare for all science subjects. In English independent schools, most preparation rooms were subject-specific, so were used to prepare for individual science subjects, that is, physics, chemistry or

biology. The difference between English state and independent schools was statistically significant. Sample sizes were too small to report for year 1 of the study in Scotland.

Table xiii. Type of preparation rooms in respondents' schools in years 1 and 3 of the study. Respondents were technicians.

Type of preparation room	Year 1		Year 3	
	n	%	n	%
England state schools				
Subject specific	39	19	206	23
Shared between all sciences	138	65	532	58
Mix of specialist and shared	35	16	176	19
England independent schools				
Subject specific	24	62	152	63
Shared between all sciences	9	23	48	20
Mix of specialist and shared	6	15	399	17
Scotland state schools				
Subject specific	-	-	3	6
Shared between all sciences	-	-	44	80
Mix of specialist and shared	-	-	8	15

13. The majority of technicians in state and independent schools in England and state schools in Scotland reported that setting up equipment is a daily task. Over 80% of state school technicians in England and over 65% of independent school technicians in England and state school technicians in Scotland reported that they advised teachers how to do an experiment/use equipment on a daily or weekly basis. Apart from this, technicians reported variety in the tasks they undertook. For example, in English state schools, other tasks undertaken by technicians on a weekly or daily basis included: photocopying; moving furniture and textbooks; and discussing science curriculum requirements. Tasks that were rarely or never undertaken by a large proportion of technicians included setting up general IT equipment, liaising with school senior managers about science practical equipment or resources and working directly with students on practical science activities in lessons.

14. Heads of science were asked if they were satisfied with the level of technical support for science in their school. In English state schools, across the three years of the study, on average 62% - 69% of respondents were satisfied or very satisfied with the level of technical support. In independent schools, the value was 68% – 81%. In years 1 and 3 of the study, consistent positive correlations were found between the number of FTE technicians and the level of satisfaction heads of science reported. Sample sizes were too low to report for Scotland.

15. In English state schools, the ratio of the number of students to number of laboratories within a school was 205 in year 3 of the study. In English independent schools and Scottish state schools, the figures were statistically significantly lower than for English state schools, at 97 and 103 pupils per laboratory, respectively.

16. Data were collected relating to the facilities available for science. These related to the quality of laboratories based on previous surveys by SCORE (2008; 2013). Approximately 90% of technicians in state and independent schools in England reported that all their laboratories met basic health and safety requirements. Hence, approximately 10% of respondents reported that some of their facilities did not meet basic health and safety requirements

(however, the study did not investigate whether students were using these facilities for practical work). In Scotland, 18% of respondents indicated that some of their facilities did not meet basic health and safety requirements. About 80% of respondents indicated that all laboratories had an electronic whiteboard and projector; about 60% reported that all had provision for teacher demonstrations. Only about 10% of technicians reported that laboratories had space for long-term experiments and computers for student use. No changes in facilities were found over the course of the study in England. Data were only available for Scotland in year 3 of the study.

17. In year 3 of the study, 79% of respondents from state schools in England and 71% from independent schools in England and state schools in Scotland reported most or all of their laboratories were accessible by students with special educational needs and disabilities (SEND). This is comparable to the figure reported by Gatsby (2017). However, 4% of technicians from state schools in England, 10% from independent schools in England and 9% of technicians from state schools in Scotland reported that none of their laboratories were accessible by SEND students.

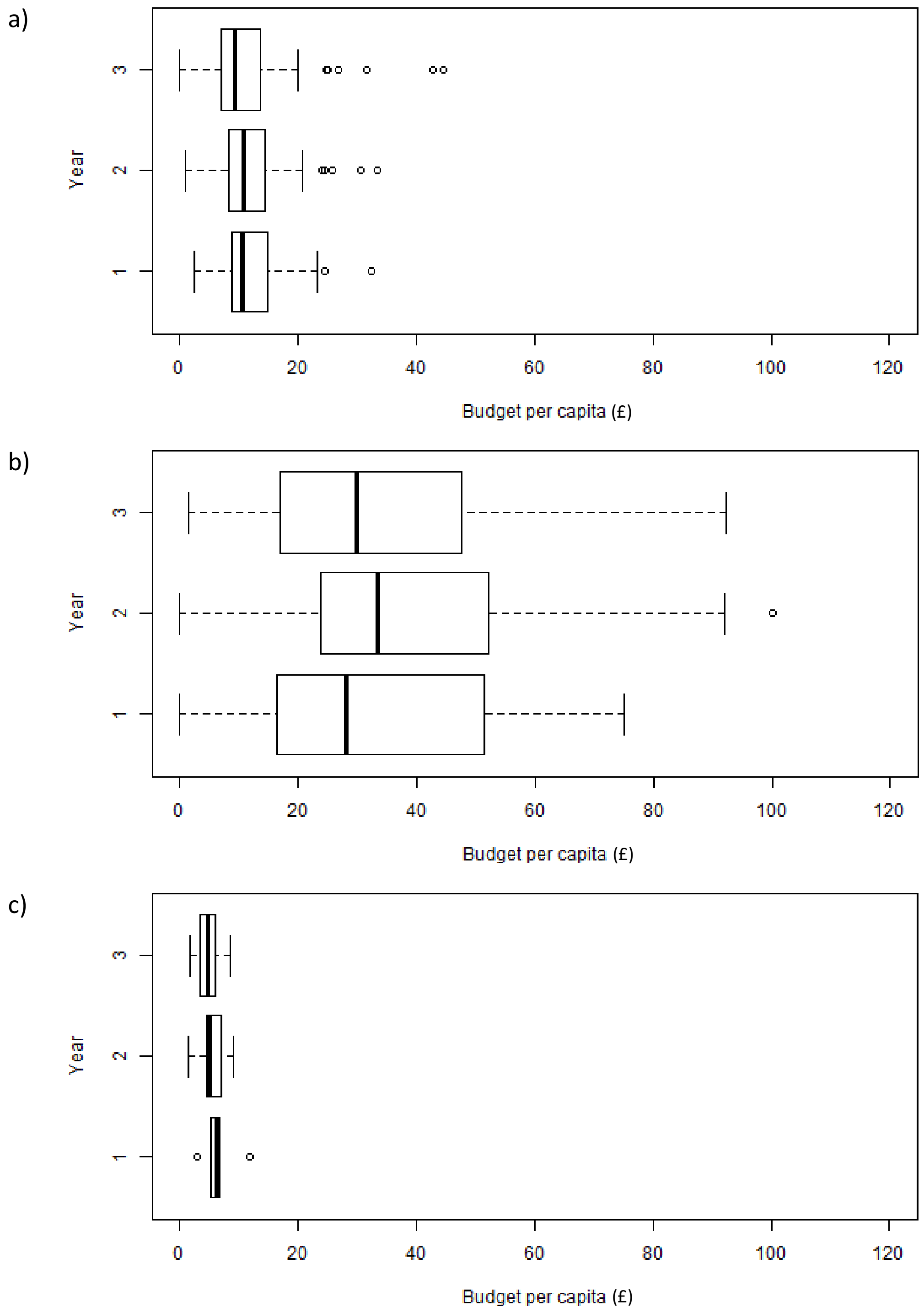
18. Technicians reported on the availability of specific equipment for biology, chemistry and physics. Equipment lists were derived from those used in previous studies (SCORE, 2008; SCORE, 2013). A majority of English state schools responding to the survey were well-equipped for biology practical work involving dissection, petri dishes, microscopes and anatomical models. Biology equipment that was not available in a majority of schools included genetic engineering kits, digital microscopes, gel electrophoresis sets and haemocytometers.

19. Chemistry equipment held by all or most English state schools included eye protection for every student; class sets of Bunsen burners, Erlenmeyer (conical) flasks, burettes and pipettes; and molecular modelling kits. About 50% had one or more digital precision balances. Over 50% of respondents in state schools in England indicated that they did not have access to a UV spectrophotometer, a set of heating mantles and magnetic stirrers.

20. Physics equipment held by all or most English state schools for class experiments included ray boxes and lenses; magnetic field observation sets; multi-meters or volt/ammeters; Newton-meters; magnets; bulbs, bulb holders and wires; an air track with an air source; an electric vacuum pump; and a Van de Graaff generator. About 60% of schools had an oscilloscope with spectrum analysis. About 40% had a set of data-loggers; a further 30% reported these were not working or incomplete.

21. Heads of science reported on their budget, that is, the funds available to them to spend on science. The range in the budget per capita within schools is shown in Figure i. These figures show English independent schools had statistically significantly higher budgets for science than English and Scottish state schools. No statistically significant changes in budgets were observed across the period of the study. In years 2 and 3 of the study, when asked to report on whether their budget had changed since the previous year, half of respondents from state schools in England reported that their budget had decreased since the previous year. In independent schools the same percentages of respondents reported an increase and a decrease in year 2 of the study. No respondents from Scottish state schools reported an increase in either years 2 or 3 of the study.

Figure i Box plot of per capita science budget as reported by heads of science for a) English state schools, b) English independent schools, c) Scottish state schools.



22. Heads of science in England were asked if they were satisfied with their budgets. In state schools in England they typically described themselves as "neither satisfied nor dissatisfied". In independent schools in England heads of science were typically "satisfied".

23. Data collected via the small number of focus groups in England showed that teachers were pleased with the revised examination specifications. The small number of participants

involved regarded the new assessment arrangements as an improvement, with one saying that practical work was now "a distinct and integral part" of the course. Some teachers attending the focus groups reported that testing students' knowledge of practical work in written examinations focussed attention on students' undertaking an experiment to learn a skill or developing understanding of a practical-related topic. Also, some of the teachers at the focus groups felt that the revised examination specifications prompted teachers to undertake some experiments that they previously believed were "too difficult" or undesirable.

5.2.3 Research Question - How does practical science contribute to preparing students for their next steps in science education?

24. Science teachers and heads of science were asked to rate on a four point scale how well prepared students were for practical activities/experiments in their subjects on starting that particular education phase. Across age ranges, of the four activities presented for rating, responses revealed that staff in England and Scotland considered students to be best prepared for "following prepared instructions". Students in all age ranges in state and independent schools in England were least prepared for writing reports and carrying out laboratory work independently. These findings are consistent with figures presented above that show the most frequent type of practical work undertaken required students to follow prepared instructions. Data also indicated students most frequently carried out experiments in pairs or groups. In addition to following prepared instructions, 14 – 16 year old students and post – 16 students in England were best prepared for "using scientific equipment".

25. Focus group and telephone interviews in England and Scotland suggested that science teachers in schools were unaware of current requirements of first year undergraduate science laboratory courses. Their past experiences as science undergraduates were used to guide and prepare their post – 16 students for university.

26. HE staff survey data indicated that the skills which HE staff considered to be important for first year undergraduates to arrive with at university were limited to: operating safely in a laboratory; following and understanding instructions; using mathematical concepts and skills; and taking notes. However, year 3 data suggested that, for biological sciences and physics, HE staff expected first year students to understand theories behind scientific methods encountered within practical work and to solve problems within practical work independently. Responses from HE staff telephone interviews agreed with survey data, showing that students were not expected to start university with specific scientific technical skills e.g. how to use an oscilloscope.

27. The HE staff survey invited respondents' views about undergraduates' preparedness for university practical work. HE staff in all three subjects on average did not rate their students to be 'somewhat prepared' or 'very well prepared' in any skills. In contrast to previous studies, HE staff reported significant improvement in their perception of students' competence in some scientific methods and practices, including planning experiments in all three subjects. For biological sciences and chemistry only, HE staff reported improvements in first year undergraduates' ability to solve problems independently and use mathematical concepts. Note-taking was reported as improved in biological sciences and physics undergraduates.

28. HE staff interviews showed desired and undesirable aspects of school practical work. A desired aspect was students having experience of long-term experiments. Prevalent but undesirable aspects included students' insistence on a correct answer to a question; and the notion that their task was to find the correct answer. Staff commented that many students sought to

know how to get marks rather to use practical work to broaden their science knowledge and skills.

29. The small number of HE students surveyed considered themselves to be only somewhat prepared for laboratory work at university. Physics students considered themselves less prepared than biological sciences and chemistry students in terms of scientific skills. A small proportion of first year undergraduate students reported experiencing laboratory or fieldwork activities in which they felt unable to do well because they didn't have the right practical skills in their first term at university.

30. Higher Education staff were asked to report on their perceptions of changes in first year undergraduates' skills, knowledge and understanding on arrival at university over the last five years (in year 1 of the study) and since the last academic year (in years 2 and 3 of the study). Over the course of the study, a statistically significant increasing percentage of HE staff noted a decline in the level of knowledge of biological sciences students in the previous five years (in year 1 of the study) or since the previous year (in years 2 and 3 of the study). In chemistry over the three years of the study, an increased percentage of HE staff reported an increase in laboratory skills since the previous year, with fewer staff reporting a decline in laboratory skills, ability to plan experiements and ability to work independently in the laboratory. Physics showed a reduction over the course of the study in the percentage of HE staff reporting a decline in students' laboratory skills since the previous year.

6 Introduction

6.1 Background

6.1.1 The importance of practical work

Practical work in science is widely considered to be a vital part of science learning and an essential feature of school science (SCORE, 2008). However, the varied nature of practical work means that there is often little agreement over the aims and purposes for practical work in schools (Dillon, 2008). A review of international evidence around the purpose of practical work for the Good Practical Science report (Gatsby, 2017) identified five key purposes of practical science in schools, which were to: teach the principles of scientific enquiry; improve understanding of theory through practical experience; teach specific practical skills, such as measurement and observation that may be useful in future study or employment; motivate and engage students; and develop higher level skills and attributes such as communication, teamwork and perseverance.

6.1.2 Implementing good practical work in schools

Conducting world-class practical work in schools is not easy. Based on an international comparative method, the Good Practical Science report (Gatsby, 2017) defines ten benchmarks that schools and teachers should achieve. Based on these benchmarks, schools in England were surveyed by the authors of the Good Practical Science report to estimate how they measured up to these requirements for world-class practical work. Findings showed that 36% of the schools surveyed did not achieve any of the full benchmarks for good practical science; and no schools achieved more than seven full benchmarks. The report makes recommendations for improving practical science in schools including prioritising progress towards the benchmarks for planned practical science, alongside provision of expert teachers and technical support.

The SCORE (2008) report found that although science practical work was regarded positively, some institutions reported shortages of equipment and technical expertise. Also, poor student behaviour was found to contribute to reduced learning opportunities. A second SCORE (2013) report focussing on resourcing secondary school practical science found serious weaknesses in provision in many responding state-funded schools and sixth form colleges. Lack of equipment, poor technical support and low funding levels contributed to inadequacies in resourcing. The report made recommendations to alleviate the perceived shortfall, including improving technicians' working conditions and salaries, provision of professional development, timetabling science lessons to take place in laboratories, not classrooms, costs associated with paper-based resources for qualifications to be included in examination budgets, not science capitation and provision of outdoor learning spaces.

The context within which science is taught in schools is also important to consider. Typically, science is presented as one subject in state schools to students aged 11 – 14 and to many 14 – 16 year old students. However, most independent schools teach physics, chemistry and biology as distinctive subjects throughout secondary education. In England, the Department for Education winter 2017 school "snapshot" reported that one-third of schools indicated they would begin (or had begun) teaching the GCSE[3] curriculum to year 9 students (age 13 – 14) rather than starting the programmes in Year 10 according to "traditional" practice (Department for Education, 2018).

6.1.3 Preparation for future study in higher education

In 2011, two reports commissioned by the Gatsby Charitable Foundation (Grant, 2011a; 2011b) found that science staff in Russell Group universities considered A level qualifications[4] were not adequately preparing students for science courses. They reported that at the beginning of their undergraduate courses, students lacked confidence in the laboratory and were not well equipped with the skills

[3] Typically a two-year course undertaken by students aged 14 – 16.

[4] Typically a two-year course undertaken by students aged 16 – 19.

believed to be necessary for undergraduate science. Universities also reported that they had been forced to adapt their courses to compensate for the decline in practical skills in new undergraduates in the previous five years. A report on practical work in biosciences in the UK Higher Education sector by Coward (2014) supported this finding, highlighting that preparation from school is perceived to be largely inadequate by university teachers.

In March 2013, the Secretary of State for Education wrote to the Office of Qualifications and Examinations Regulator in England (Ofqual) (Department for Education, 2012) stating that "the single most important purpose of A level qualifications is to prepare young people for further study at university". However, reports that had been received from leading university academics and learned bodies such as the Institute of Physics were stating that A levels were not preparing students well enough for the demands of an undergraduate degree. In the letter the Secretary of State for Education sought to reform A levels with the intention to involve universities (particularly the best, research intensive universities) in the development of the new A level qualifications. The letter stated that the Department for Education should not have a role in the development of A level qualifications and that "it is more important that universities are satisfied that A levels enable young people to start their undergraduate degrees having gained the right knowledge and skills".

As well as engaging universities in the development of the new A level qualifications, the reforms also sought to make the A levels linear, with all exams taken at the end of the course (rather than in the existing modular structure). AS level qualifications[5] would remain, but as a separate, stand-alone qualification.

6.1.4 Changes to practical work in schools

Table 1 provides a summary of the changes to qualifications in England and Scotland since the 2013 – 14 academic year. The changes aimed to address concerns relating to the reliability of marking and security of assessment materials in the pre-reform system (Ofqual, 2013). The aim was for the reformed method of assessing practical work to also embed practical work within the A level science curriculum.

There were concerns expressed in the early stages of implementation of the new A levels that the lack of a dedicated practical science assessment component may be detrimental to the skills that students acquire and that the reforms may send a message that practical work has less importance to learning of knowledge (Gatsby, 2014; Wellcome, 2014). In the longer term, there were also concerns that this would lead to a reduction in the number of students going on to complete degrees in Science, Technology, Engineering and Mathematics (STEM) degrees. However, some also highlighted benefits of the reforms, suggesting that a greater breadth of skills may be covered and be more flexible for the way that teachers can incorporate practical work into lessons (Canning, 2015; Evans, 2015). There was also a hope for a better synergy between practical work and course content.

The method of assessing A level science practical work changed significantly with the reformed qualification (Ofqual, 2017). Previously practical work had been assessed via a controlled practical activity (or activities) and was worth 20% of the final mark. The work was either marked by exam boards (practical examination) or internally marked by teachers and moderated by exam boards (practical assessment). There was significant variation in the requirement for the activity (or activities), ranging from short, scaffolded activities within a given timeframe, to an individual investigation lasting over a period of weeks. Around 10% of the marks for the controlled practical activity were allocated to direct observation of practical work, the majority of marks for the assessment of practical work were awarded to the written work produced by the student (Ofqual, 2017).

[5] Typically a one-year course undertaken by students aged 16 – 19. Prior to the current reforms, AS level qualifications were divided into modules and could count towards the corresponding A level qualification.

Table 1. Summary key dates for changes to the science curricula in England and Scotland since the 2013 – 14 academic year. Note: It is not compulsory to study science at National 4 or 5 level in Scotland

	First academic year in which the new assessments will be taught	First academic year in which the new examinations will be taken
England		
GCSE (biology, chemistry, physics and combined science (double award))	Year 9 - 2015 - 16 (for schools who chose to start teaching in year 9) 2016 - 17 (year 10) 2017 - 18 (year 11)	2017 - 18
A level	Year 12 - 2015 - 16 Year 13 - 2016 - 17	2016 - 17
Scotland		
National 5	Teaching in Scotland is more flexible than the English education system, however, students will usually take one year to complete each course	2013 - 14
Higher		2014 - 15
Advanced Higher		2015 - 16

The reformed A level specifications for biology, chemistry and physics are intended by Ofqual and the Awarding Bodies to encourage the development of skills, knowledge and understanding in science through a range of teaching and learning opportunities for regular hands-on practical work (Ofqual, 2013; Ofqual, 2016). Students are required to demonstrate competence in skills common to all sciences (Ofqual, 2016 Appendix 5b) and in apparatus and techniques specific to each science (Ofqual, 2016 Appendix 5c).

It is intended that a student's competence is assessed by their teachers as they carry out practical activities in class, with a minimum requirement of 12 practical activities across the two-year course. They are assessed against specific criteria for practical science assessment (Ofqual, 2016 p15,16) resulting in either a pass or not classified grade for the Practical Endorsement at the end of the two-year course.

Students are also indirectly assessed on practical skills in the written examinations, with 15% of marks allocated to questions which indirectly assess knowledge and understanding of practical skills (Ofqual, 2017).

Within the reformed GCSE qualification there is no practical endorsement component, however, 15% of marks on written exams are intended to assess knowledge of practical work. This replaces the method of assessment of practical work via controlled assessments in the pre-reform system.

The Scottish education system has recently changed, with the introduction of National 5 examinations and reforms to Higher and Advanced Higher qualifications (SQA, 2018). Examination of the National 5 qualification took place for the first time in 2014. The first examination of the reformed Higher qualification was in 2015 and Advanced Higher followed in 2016. Assessment of practical science in new National 5 and reformed Higher qualifications is through an assignment in which students research and report on a topic of interest demonstrating skills, knowledge and understanding of their subject. For Advanced Highers, a project-report is produced. For all levels, students plan, design and carry out experimental investigations as part of the assessment process. For National 5 and Higher qualifications, the assignment is worth 20 marks, constituting 20% of the overall mark for the course assessment. For Advanced Highers, the project-report is worth 30 out of 120 marks available for the course.

6.1.5 Impact of reforms

The full impact of the GCSE and A level reforms will not be known for some time and must also be considered in the wider context with changes to accountability measures and growing funding challenges for schools. The first cohort of A level students to have been through the reformed A level qualification in England sat their exams in summer 2017 and started university autumn 2017. The first cohort of GCSE students in England were examined in summer 2018. Therefore, the majority of A level students commencing their studies in Autumn 2018 will have been through the new GCSE science qualifications.

Other longitudinal studies investigating the impact of reforms on practical science (known to the authors at the time of writing) include :

- OCR (Wilson, 2015)
- Ofqual (2017; 2018)
- Royal Society of Biology (2017)

To date, the OCR study (Wilson, 2015) has published baseline findings on the purpose and type of practical activities conducted before implementation of the reforms. The Royal Society of Biology has currently only reported on pre-reform baseline findings including summary findings on student confidence to undertake different aspects of science study, practical experience and understanding of different topic areas (Royal Society of Biology, 2017).

Initial findings from the Ofqual (2017) qualitative study published in July 2017, showed that the scale of impact of the A level reforms appeared to be dependent upon characteristics of individual institutions. In general, teachers interviewed were positive about the changes and were reporting greater flexibility to embed practical work into courses and to balance this across topics throughout the year. The report noted that expectations from teachers is that the quantity of practical work undertaken is not expected to change (in schools already prioritising practical work) or would increase as students were required to complete practical work more regularly. Some teachers reported lack of clarity regarding the new assessment arrangements. There was no dominant opinion from teachers about how reforms may affect student motivation.

6.2 The present study

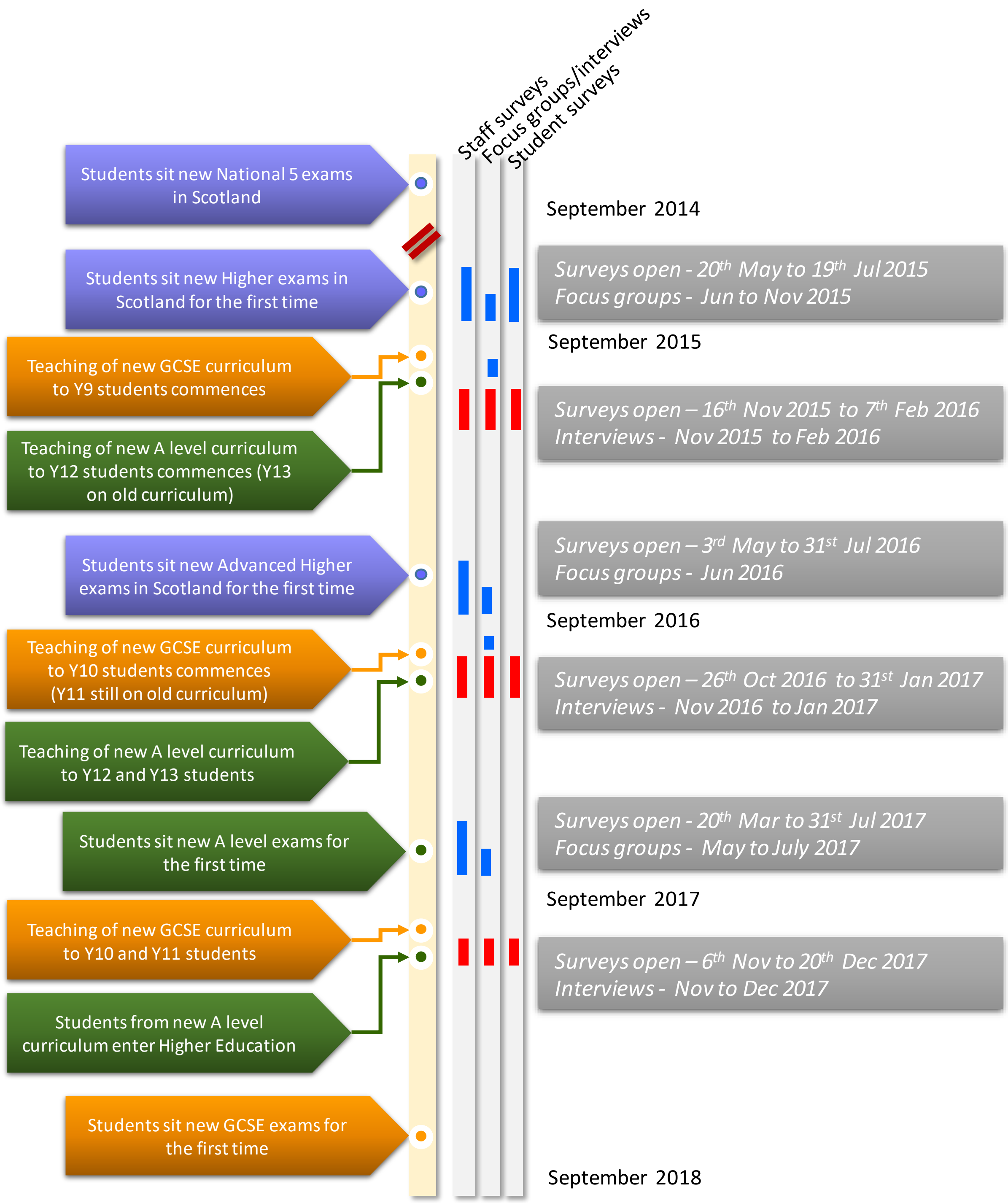
This study presents data collected over a three-year period, commencing before implementation of the reforms in May 2015, through to December 2017 when the first cohort of students through the reformed A level qualification had started their undergraduate courses. Data were collected via annual surveys, focus groups and telephone interviews.

This study adopts the SCORE (2013) definition of practical work, namely:

"A learning activity in which students observe, investigate and develop an understanding of the world around them, through direct, hands-on, experience of phenomena or manipulating real objects and materials." (p 3)

Figure 1 presents a timeline of the reforms and data collection points within the project.

Figure 1. ***Timeline of curriculum reforms in England and Scotland and data collection points within the study. Blue bars indicate data collection periods in schools[6], red bars indicate data collection periods in higher education institutions.***



[6] Note: For brevity the term “schools” is used to refer to both schools and colleges throughout the study.

6.3 Aims of the research

The overall aims of the study were to investigate:

- Why teachers choose to undertake practical activities and where does that motivation come from?
- What proportion of lesson time is dedicated to practical activities across the sciences at Key Stages 3, 4 and 5, and what breadth of activity is undertaken?
- How does the breadth of practical activities offered to students vary within and between schools?
- How well does practical science prepare students for their next steps with and in science?
- If the quantity and quality of practical activities in science are changing, what are the main causes?
- How are the levels of key resources changing across the sector over the 3 years of the study and what impact is this having on practical science in schools?
- How is the introduction of new AS, A2 levels and GCSEs affecting practical science in schools?

These were refined to three key research questions:

1) What science practical work is provided within schools in terms of the quantity and breadth undertaken and how has this changed over the lifetime of the study?
2) What are the main insights into any influences on the quantity and breadth of science practical work undertaken in schools?
3) How does practical science contribute to preparing students for their next steps in science education?

This study aimed to measure and understand reasons for changes in schools over the lifetime of the project. Changes due to the implementation of the new GCSE and A level curricula in England are still ongoing and we expect schools to still be in a period of flux. Therefore, it is important to note that the findings presented in this report represent the picture within schools before and during the period of change only. Further work is require to obtain a picture of the situation post-change.

7 Research Methods

7.1 Data collection techniques

Five instruments were used for data collection:

1. Survey of heads of science, science teachers and science technicians in schools (referred to as the "school staff survey")
2. Focus groups and telephone interviews with heads of science, science teachers and science technicians in schools (referred to as the "school focus groups and telephone interviews")
3. Survey of higher education staff involved with the teaching of first year undergraduate laboratory courses (referred to as "HE staff survey")
4. Telephone interviews with higher education staff involved with the teaching of first year undergraduate laboratory courses (referred to as "HE telephone interviews")
5. Survey of first year undergraduate students who take a laboratory class as part of their course (referred to as "HE student survey").

The detailed methods for each of these instruments are given in Appendix 1 – Research Methods. Copies of the instruments from all three years are in Appendices 4 to 8.

Note: In year 1 of the study, a survey of students in schools was conducted. However, the response rate was low and the findings are not presented in this report.

Table 2 provides a summary of the data collection instruments and geographical locations in which they were implemented. An original aim of the study was to collect data from all four nations in the UK. However, response rates from schools in Northern Ireland and Wales in year 1 of the study were extremely low. Hence, the decision was made to exclude Northern Ireland and Wales from data collection from schools in years 2 and 3. Details of methods undertaken to maximise participation are given in Section 4.4, Appendix 1.

Table 2. Summary of the data collection instruments employed during the study and the geographical locations in which they were used.

	Data collection instrument	Year 1	Year 2	Year 3
1	**Survey of heads of science in schools**	England Northern Ireland Scotland Wales	England Scotland	England Scotland
	Survey of science teachers in schools	England Northern Ireland Scotland Wales	England Scotland	England Scotland
	Survey of science technicians in schools	England Northern Ireland Scotland Wales	N/A	England Scotland
2	**Focus groups with heads of science, teachers and technicians in schools**	England	England	England
	Telephone interviews with heads of science, teachers and technicians in schools	Northern Ireland Scotland Wales	Scotland	Scotland
3	**Survey of staff involved with the teaching of first year undergraduate laboratory courses for students studying single subject biological sciences, chemistry and physics in Higher Education Institutions in the UK**	England Northern Ireland Scotland Wales	England Northern Ireland Scotland Wales	England Northern Ireland Scotland Wales
4	**Telephone interviews with a selection of staff involved with the teaching of first year undergraduate science laboratory courses in Higher Education Institutions in the UK**	England Northern Ireland Scotland Wales	England Northern Ireland Scotland Wales	England Northern Ireland Scotland Wales
5	**Survey of first year undergraduate students studying biological sciences, chemistry and physics in Higher Education Institutions in the UK**	England Northern Ireland Scotland Wales	England Northern Ireland Scotland Wales	England Northern Ireland Scotland Wales

7.2 The sample

The inclusion criteria for the school staff survey, Higher Education staff survey and Higher Education student survey data are provided in Section 3.1 in Appendix 2. Although Further Education (FE) colleges have different operating arrangements to mainstream state schools, for the purposes of this report they are included in the state school sample. An analysis of responses from FE colleges was conducted to ensure that their inclusion in the state school sample did not skew the data. Detail of the analysis can be found in Section 3.1 in Appendix 2.

The school sample for state schools in England has been weighted by deprivation in order to make the sample nationally-representative. A measure of deprivation was calculated for each respondent's school by combining the school's Free School Meals (FSM) and Income Deprivation Affecting Children Index (IDACI) value for the school's postcode. This measure was then split into 10 national deciles. Further Education colleges do not have FSM data so this group of institutions was treated as an entirely separate group, giving 11 groups in total. Weights were then calculated and applied so that within each type of respondent's role (Head of science, Teacher or Technician) and within each year of the survey, the sample was nationally-representative in terms of the proportions falling into each of the 11 groups.

Appendix 2 also provides details of how the samples have been analysed for variance in responses within school, the representativeness of schools and individuals responding to the survey.

A note on terminology: A "sixth-form college" provides post – 16 education to 16 – 19 year old students only. A "Further Education" (FE) college provides a broad range of post – 16 programmes to the 16 – 19 year old age group and serves the wider community by providing a range of vocational and other non-assessed programmes. "State" schools receive funding from direct taxation at rates per student set within each UK nation. "Independent" schools receive funding from fees charged directly to families of attending students.

7.2.1 School staff survey

Data were collected from heads of science and science teachers in schools via an anonymous survey administered electronically to schools across a three-year period (2015, 2016 and 2017). Science technicians were surveyed in years 1 (2015) and 3 (2017) but not in year 2 (2016) of the study as facilities were not expected to change greatly between year 1 and 2 of the study. Science teachers and heads of science were asked to answer questions for a class of their choice in the 11 – 14, 14 – 16 and post – 16 age ranges. For each age range they specified the subject and year-group/qualification they were teaching. Heads of science were also asked about departmental arrangements including: number of students; staffing; budget; and satisfaction with resources. Technicians were asked about: staffing; tasks undertaken as a technician; and availability of facilities within the department, including preparation rooms, laboratories and equipment. Analysis of respondents' qualifications shows our sample is more highly qualified than the overall workforce (Gov.uk, 2018). Results should be read with this in mind.

Due to the anonymous nature of the survey, it is not possible to know whether the same member(s) of staff responded to the survey each year. A cross-sectional sample containing responses from all schools in each year is used for the analyses in this report, due to the variance in responses from members of staff within schools. Section 3.2 in Appendix 2 provides a detailed explanation of this analysis of variance between multiple staff members within a school or college.

Table 3 below provides a summary of the schools responding to the survey. Section 3.3 in Appendix 2 contains a detailed breakdown of the schools responding to the survey. Table 4 provides a summary of the individuals responding to the school staff survey. Section 3.4 in Appendix 2 provides a detailed breakdown of the individuals responding to the survey.

Table 3. Schools responding to the school staff survey by school type and nation in each of the three years of the study. Schools are unique within each survey year but not across survey years. Note: science technicians were only surveyed in years 1 and 3 of the study.

Nation	School type	Year 1	Year 2	Year 3	Total
England	State schools	425	212	912	**1549**
	Independent schools	163	121	218	**502**
Total		**588**	**333**	**1130**	**2051**
Scotland	State schools	34	44	69	**147**
Total		**34**	**44**	**69**	**147**
Grand total		**622**	**377**	**1199**	**2198**

Table 4. Individuals responding to the school staff survey by occupation and country in each of the three years of the study. Note: science technicians were only surveyed in years 1 and 3 of the study.

Country	Occupation	Year 1	Year 2	Year 3	Total
England	Head of science	251	219	230	700
England	Teacher	200	310	538	1048
England	Technician	266	0	1172	1438
England	**Total**	**717**	**529**	**1940**	**3186**
Scotland	Head of science	18	17	21	56
Scotland	Teacher	13	37	54	104
Scotland	Technician	7	0	55	62
Scotland	**Total**	**38**	**54**	**130**	**222**
Total	**Head of science**	**269**	**236**	**251**	**756**
Total	**Teacher**	**213**	**347**	**592**	**1152**
Total	**Technician**	**273**	**0**	**1227**	**1500**
Total	**Total**	**755**	**583**	**2070**	**3408**

7.2.2 School staff focus groups and telephone interviews

Table 5 summarises schools participating in the school staff focus groups in England and telephone interviews in Scotland. Section 5.1 in Appendix 2 contains a detailed breakdown of participating schools. Qualifications of staff participating in focus groups and telephone interviews is not known. However, in general, respondents to the school staff survey were more highly qualified than the overall workforce (Gov.uk, 2018) and our recommendation is that an assumption of similarly highly qualified participants is made in relation to the focus groups and telephone interviews. Responses should be interpreted with this in mind.

Table 5. Schools participating in the focus groups and telephone interviews by nation.

Region	Year 1	Year 2	Year 3
England			
State schools	15	16	18
Independent schools	6	5	6
Total	**21**	**21**	**24**
Scotland	3	8	11
Total	**24**	**29**	**35**

7.2.3 Higher Education staff survey

Table 6 summarises institutions responding to the Higher Education staff survey. Section 4.3 in Appendix 2 contains a breakdown of the institutions and individuals responding to the survey including details of: the nation and department in which the respondent stated they taught; the number of years teaching experience of respondents; the roles respondents held within a department; whether the department was part of a Russell Group institution; the average tariff score for first year undergraduates in departments; and the percentage of students UK-domiciled prior to course entry.

Table 6. Respondents to the Higher Education staff survey broken down by the departments in which they stated that they taught, by survey year and by nation.

Nation	Year	Biological Sciences	Chemistry	Physics	More than 1 subject	Total
England	Year 1	14	11	13	1	**39**
	Year 2	21	21	15	2	**59**
	Year 3	19	12	12	1	**44**
Scotland	Year 1	1	3	0	0	**4**
	Year 2	2	5	2	0	**9**
	Year 3	5	4	2	0	**11**
Total	**Year 1**	15	14	13	1	**43**
	Year 2	23	26	17	2	**68**
	Year 3	24	16	14	1	**55**
	Total	**62**	**56**	**44**	**4**	**166**

7.2.4 Higher Education telephone interviews

Table 7 summarises institutions participating in the Higher Education staff telephone interviews in Scotland. Section 5.2 in Appendix 2 contains a detailed breakdown of the participating institutions and individuals.

Table 7. Institutions participating in the telephone interviews split by department and nation. B – Biological sciences, C – Chemistry, P – Physics.

	Year 1				Year 2				Year 3			
Nation	**B**	**C**	**P**	**Total**	**B**	**C**	**P**	**Total**	**B**	**C**	**P**	**Total**
England	3	5	5	**13**	3	6	5	14	4	5	3	**12**
Scotland	1	0	0	**1**	2	3	1	6	2	2	1	**5**
Wales	0	0	0	**0**	1	0	1	2	0	2	1	**3**
Total	**4**	**5**	**5**	**14**	**6**	**9**	**7**	**22**	**6**	**9**	**5**	**20**

7.2.5 Higher Education student survey

Table 8 summarises institutions responding to the Higher Education student survey. Section 4.4 in Appendix 2 contains detail of the departments and individuals responding to the survey including a breakdown by gender and the types of institution respondents attended for their post – 16 education.

Table 8. Number of students responding to the HE student survey. The number of departments is indicated in brackets. Respondents were students who remained in the sample for analysis after exclusions.

Survey year	Biological Sciences	Chemistry	Physics	Total
Year 1	26 (2)	22 (1)	69 (5)	117 (7)
Year 2	143 (12)	78 (9)	91 (7)	312 (16)
Year 3	50 (4)	46 (6)	50 (5)	146 (12)
Total	**219 (14)**	**146 (12)**	**210 (9)**	**575 (21)**

8 Findings

For reporting purposes, the findings are organised under the three refined research questions for the study:

1) What science practical work is provided within schools in terms of the quantity and breadth undertaken and how has this changed over the lifetime of the study?
2) What are the main insights into any influences on the quantity and breadth of science practical work undertaken in schools?
3) How does practical science contribute to preparing students for their next steps in science education?

Throughout the report, data are presented split by age range, school type (state and independent) and by nation (England and Scotland). The number of survey responses from technicians in state schools in Scotland in year 1 of the study and in independent schools in Scotland in all three years of the study is included in the description of the sample, however, there were too few respondents for these data to be reported in the main findings. Data collected in year 1 of the study from heads of sceince, science teachers and technicians in Northern Ireland and Wales are not included in the report as there were too few responses to provide a representative sample for those nations. Data collected from school students in year 1 of the study are also not included due to the small number of respondents. Survey responses were not collected from school students in all nations nor heads of science, science teachers and technicians in Northern Ireland or Wales in years 2 and 3 of the study due to lack of participation in the first year. Discussion of the sample and methods of weighting of the school staff survey sample is detailed in Section 7.2.

Within the report we have tested multiple hypotheses and reported those that are significant at the 0.05 level. The large number of significance tests performed increases the likelihood of Type 1 errors (i.e. concluding that there is a statistically significant difference or association when in fact this is simply due to chance). Each finding should therefore be considered within its wider context. Reporting of comparisons and changes stated in the text of the report should be read as being statistically significant at the $P<0.05$ level. Non-statistically significant findings are not reported other than in exceptional cases, in which case this will be made clear within the text.

To assess whether there has been change over the period of the study, regression analyses were conducted. Two types of regression analyses have been used. Where the outcome of interest was dichotomous, binary logistic regression was applied but otherwise ordinary least squares (OLS) linear regression was used. Unless otherwise stated in the text, regression analyses were conducted with only survey year as a predictor and are provided as a rate of change per year in tables.

If sample sizes are fewer than 10 respondents, data from surveys are aggregated to preserve anonymity of respondents. Where aggregating data is inappropriate, findings are not presented and a dash (–) is shown in associated tables.

Qualitative data are used within the report in the form of vignettes, giving examples of the impact of changes in schools and HE institutions. These are triangulated with survey data to permit cautious generalisations to be made.

8.1 What science practical work is provided within schools in terms of the quantity and breadth undertaken and how has this changed over the lifetime of the study?

8.1.1 Quantity of practical work

This section considers the extent to which the quantity of practical work undertaken by students in schools has changed over the course of the study. The change in quantity of practical work is investigated for both the number of hours of practical work they are undertaking per week and the number of practical work activities.

Key findings:

Age range	England state schools	England independent schools	Scotland state schools
Science lesson time, Hours per week			
11 – 14	3.0 (2.9, 3.1)	1.7 (1.6, 1.8)	2.7 (2.6, 2.9)
14 – 16	3.2 (3.1, 3.3)	2.5 (2.4, 2.5)	3.9 (3.7, 4.0)
Post – 16	5.0 (4.9, 5.1)	5.1 (5.0, 5.3)	4.6 (4.4, 4.7)
Science lesson time spent on practical work, Hours per week			
11 – 14	1.0 (0.9, 1.0)	0.7 (0.7, 0.8)	1.2 (1.0, 1.3)
14 – 16	0.9 (0.8, 0.9)	0.7 (0.7, 0.8)	1.1 (1.0, 1.2)
Post – 16	1.3 (1.3, 1.4)	1.5 (1.5, 1.6)	1.1 (1.0, 1.2)

No universal trends in changes to the overall science lesson time or science lesson time spent on practical work were evident across subjects within a particular age range (for a particular school type). However, statistically significant changes were observed for individual subjects and school types.

Age range	Changes significant at $P<0.05$
Science lesson time per week (Hours)	
11 – 14 age range	↓Chemistry (England - Independent) ↑Physics (England – State)
14 – 16 age range	None
Post – 16 age range	None
Science lesson time spent on practical work per week (Hours)	
11 – 14 age range	None
14 – 16 age range	↑Biology (England – State)
Post – 16 age range	None

Staff (heads of science, teachers and technicians) participating in focus groups in England indicated that integration of practical work into the A level courses had improved with the introduction of the new curriculum. They perceived the introduction of the recommended practical work activities in the new curriculum was leading all teachers to place a focus on practical work.

Science teachers participating in focus groups commented that the level of content within the GCSE and A level syllabuses led to significant time pressure within science lessons to fit in the required information, sometimes to the detriment of practical work.

Students studying biology, chemistry and physics in the 11 – 14 age range carried out between 16 and 26 practical work activities per academic year. Students studying science (as a subject) carried out between 27 and 38 practical work activities per academic year.

Students in the 14 – 16 age range carry out between 15 and 24 practical work activities in an academic year. In both state and independent schools in year 1 of the study, biology students carried out fewer practical work activities than chemistry students. There was an increase in the number of practical work activities carried out by biology students in an academic year in state schools over the course of the study. Although independent school students also conducted fewer practical work activities in biology than chemistry in year 1 of the study, they did not show an increase over the course of the study as was seen in state schools.

Students in the post – 16 age range carried out between 18 and 30 practical work activities per academic year. The number of practical work activities carried out in an academic year by biology students in year 1 of the study was less than in both chemistry and physics in state schools in England. In independent schools in year 1 of the study, biology students carried out fewer practical work activities per academic year than chemistry students. There was a decrease in the number of practical work activities carried out in an academic year by chemistry students in both state and independent schools over the three years of the study.

8.1.1.1 Timetabled time (in hours) for science lessons

Figure 2 to Figure 5 (and Table 1 in Appendix 3 to Table 4 in Appendix 3) show the average lesson time (in hours) for individual subjects in each of the three age ranges (11 – 14, 14 – 16 and post – 16) and across the three years of the study. Findings are presented separately for state and independent schools in England. Findings are only for state schools in Scotland.

The findings show that across all age ranges in both state and independent schools in England in all three years of the study, there was no difference in lesson time per week between biology, chemistry and physics. In the 11 – 14 age range, lesson time per week decreased for chemistry over the three years of the study and increased in physics in state schools.

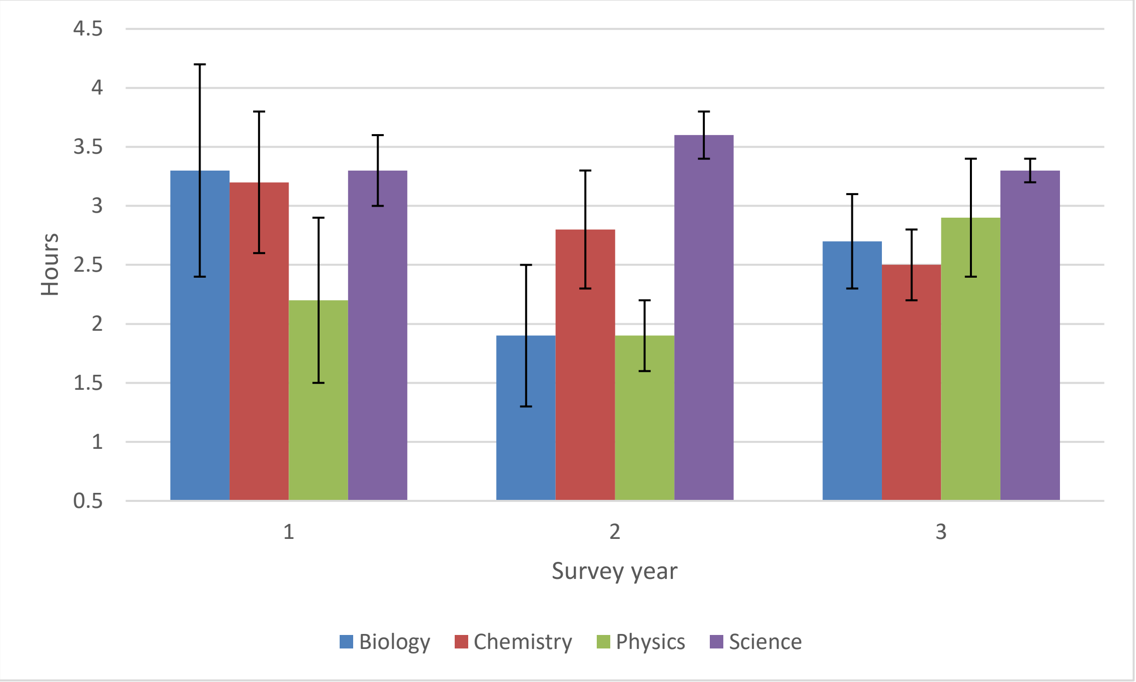
In the 11 – 14 age range, science teachers and heads of science were able to select from a choice of four subjects: biology, chemistry, physics or science. Science was not an option in the 14 – 16 and post – 16 age ranges. A 'science' class in this context is the teaching of three sciences by a single teacher, rather than each of biology, chemistry and physics being individually timetabled and taught by separate teachers. In state schools, lesson time for science (as a subject) was higher than: physics in year 1 of the study; biology, chemistry and physics in year 2 of the study; and biology and chemistry in year 3 of the study. In independent schools, science had more lesson time per week than the other three subjects in all three years of the study. It should be noted that the time spent on science as an individual subject is not equal to the total of the average time spent on biology, chemistry and physics combined.

Independent schools in England had fewer hours of lesson time per week than state schools in the 11 – 14 age range in: chemistry in all three years of the study; science in year 2 of the study; and biology and physics in year 3 of the study. In the 14 – 16 age range, independent schools had less lesson time per week than state schools in all three sciences in year 3 and also in biology in year 2 of the study and chemistry in year 1 of the study.

Due to the lower response rate in Scotland, it is not possible to provide a breakdown of the findings for individual subjects. Averaging all subjects together for each of the age ranges shows that there is no change over the period of the study in the science lesson time per week (in hours) in any of the age ranges.

Figure 2. 11 – 14 age range (England): Bar chart comparing the average science lesson time (in hours) per week over the three survey years and between subjects. There were too few respondents to report biology, physics and science data in year 1 of the study for independent schools. Respondents were heads of science and science teachers. 95% confidence intervals are indicated on the graph.

a State schools (base n= 561)



b Independent schools (base n =193)

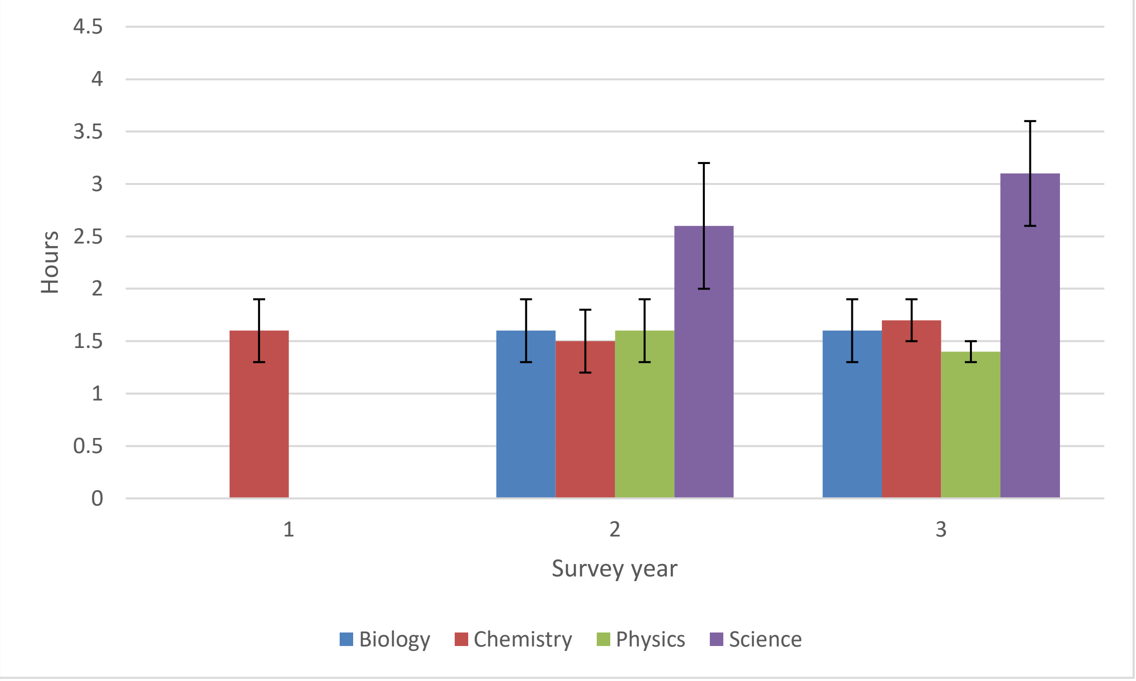
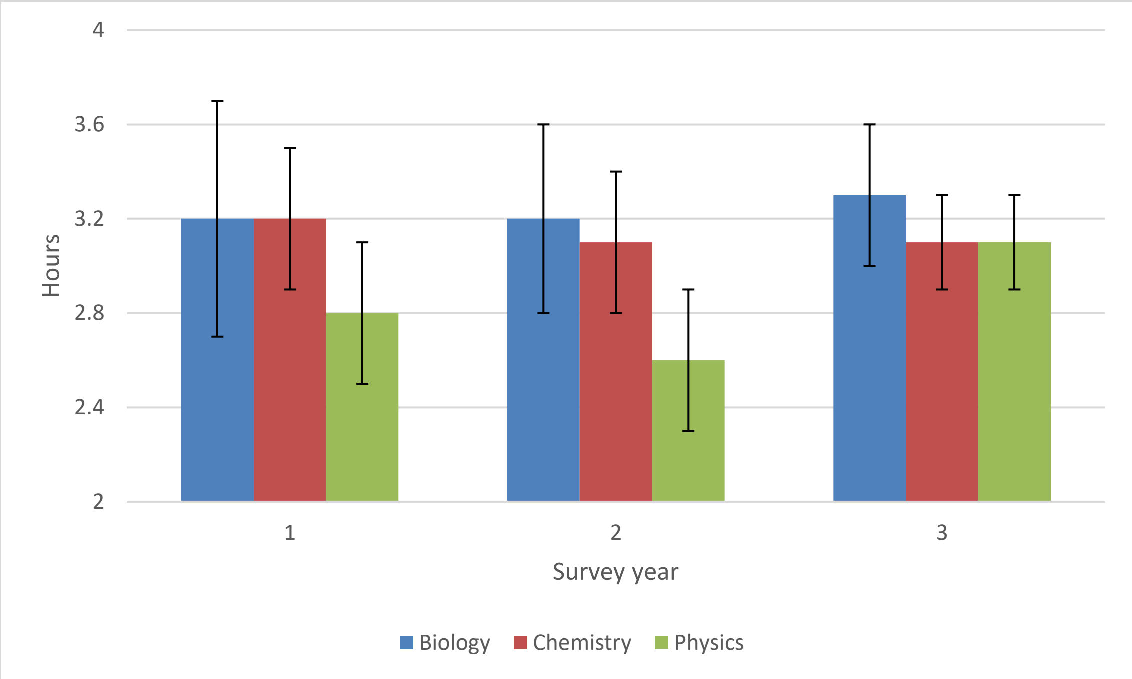


Figure 3. 14 – 16 age range (England): Bar chart comparing the average science lesson time (in hours) per week over the three survey years and between subjects. Respondents were heads of science and science teachers. 95% confidence intervals are indicated on the graph.

a State schools (base n= 910)



b Independent schools (base n = 467)

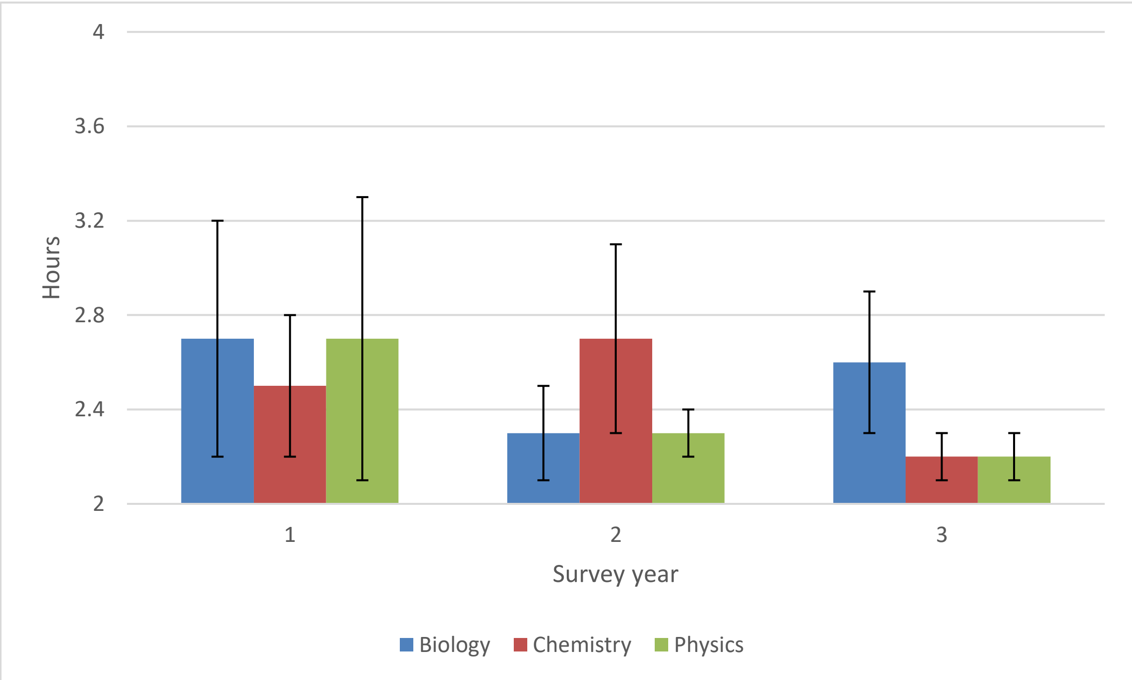
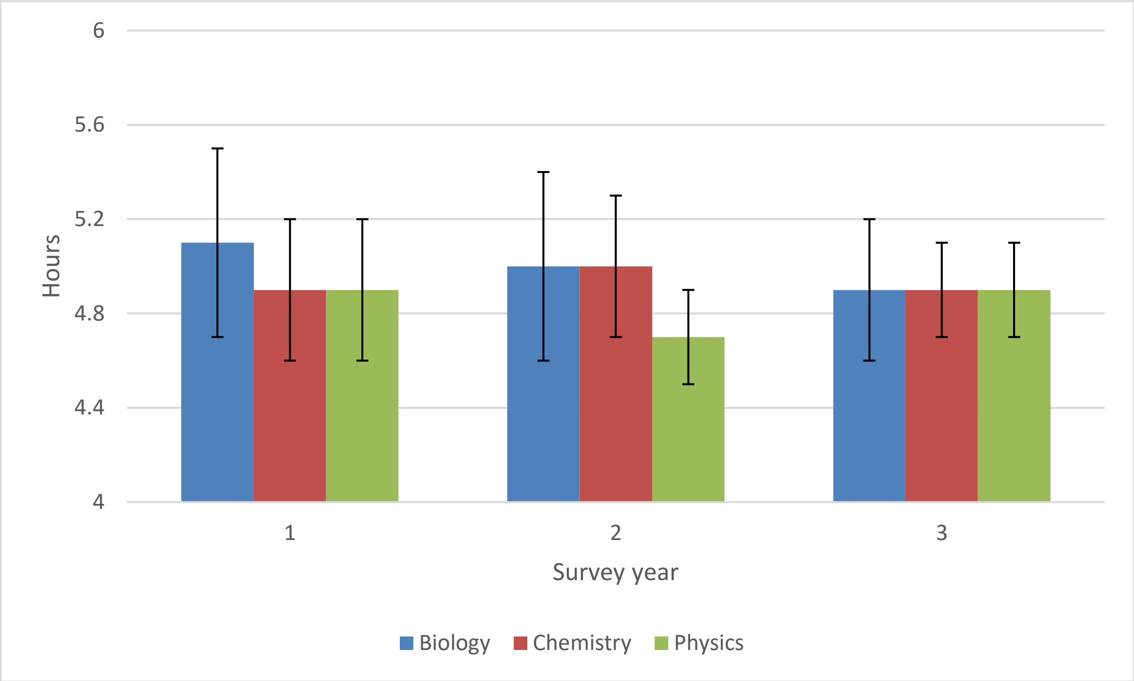


Figure 4. Post – 16 age range (England): Bar chart comparing the average science lesson time (in hours) per week over the three survey years and between subjects. Respondents were heads of science and science teachers. 95% confidence intervals are indicated on the graph.

a State schools (base n=823)



b Independent schools (base n =472)

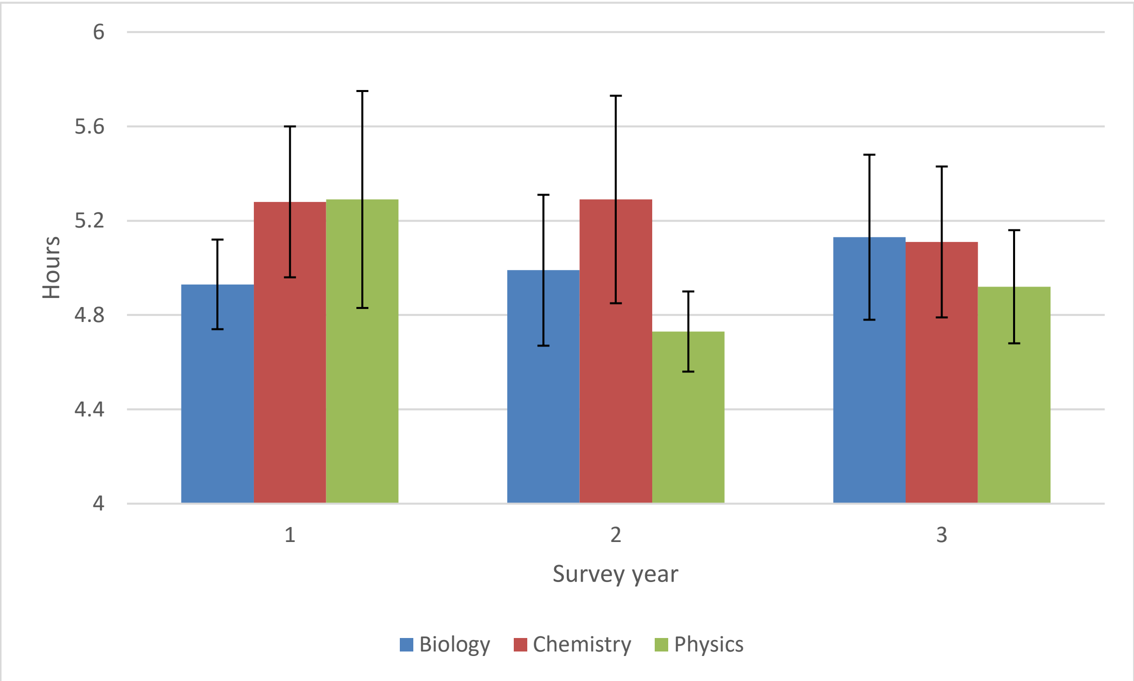
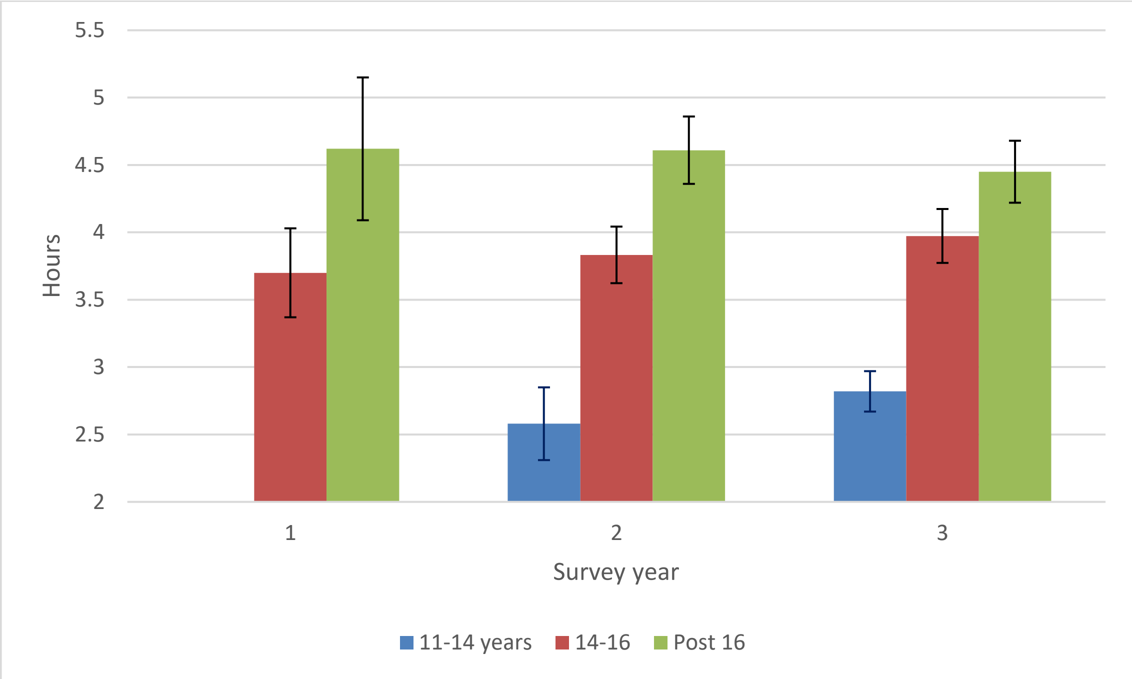


Figure 5. All subjects combined (Scotland): Bar chart comparing the average science lesson time (in hours) per week over the three survey years showing data for 11 – 14 age range (n = 76), 14 – 16 age range (n = 127) and post – 16 age range (n = 138). Respondents were heads of science and science teachers. 95% confidence intervals are indicated on the graph.



8.1.1.2 Science lesson time per week spent on practical work (in hours)

Figure 6 to Figure 9 (and Table 5 in Appendix 3 to Table 8 in Appendix 3) show the average science lesson time (in hours) spent on practical work per week for individual subjects in each of the three age ranges and across the three years of the study.

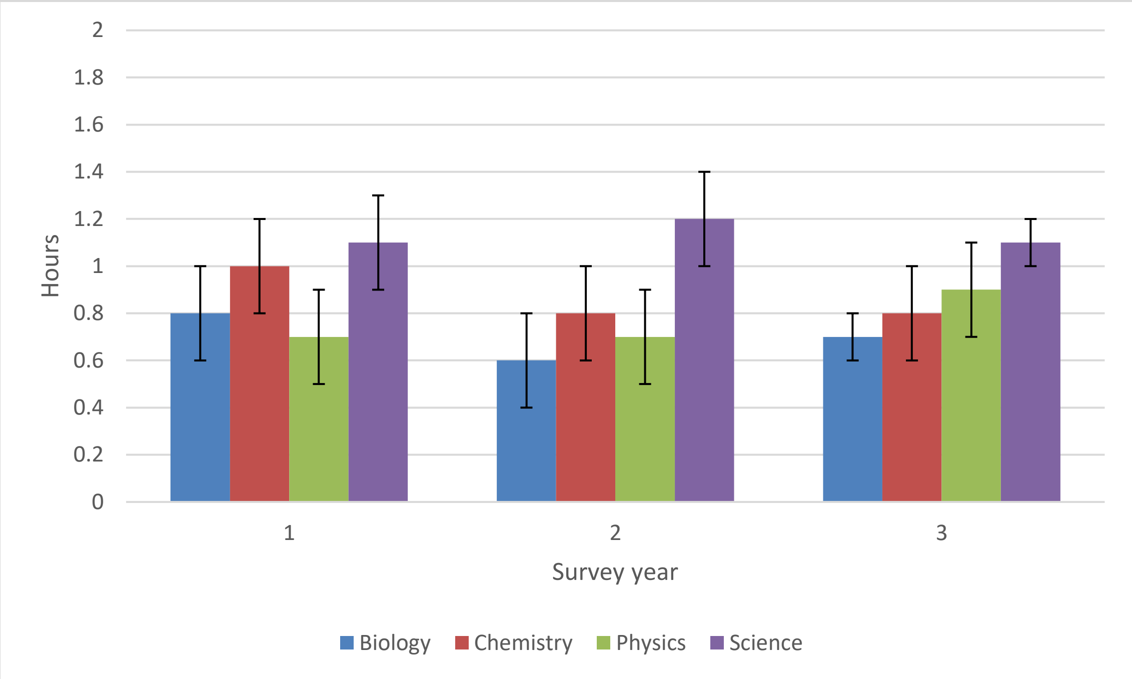
The findings show that in both state and independent schools in all age ranges in all three years of the study, there was no difference in the time spent in science lessons on practical work per week between biology, chemistry and physics with three exceptions. Firstly, in state schools in the 14 – 16 age range in year 1 of the study, chemistry students spent more time per week on practical work than biology students. This difference was not present in years 2 and 3 with biology in state schools showing an increase year on year in the number of hours of science lesson time spent on practical work per week. Secondly, in the post – 16 age range, state schools spent less time on practical work per week in biology than in physics in year 1 of the study, and less time in biology than chemistry in year 3 of the study. Finally, also in the post – 16 age range, independent schools spent more time than state schools on practical work per week in biology in year 1 of the study and physics in year 3 of the study.

In the 11 – 14 age range, science (as a subject) had a higher amount of lesson time (in hours) per week spent on practical work in state schools than physics in year 2 of the study and biology in years 2 and 3 of the study. In independent schools, science had a higher amount of time spent on practical work in all three subjects in all three years of the study.

Due to the lower response rate in Scotland, it is not possible to provide a breakdown of the findings at the level of individual subjects. Averaging all subjects together for each of the age ranges, shows that there is no change over time in the amount of science lesson time per week spent on practical work (in hours) in any of the age ranges.

Figure 6. 11 – 14 age range (England): Bar chart comparing the average science lesson time spent on practical work per week (in hours) over the three survey years and between subjects. Respondents were heads of science and science teachers. 95% confidence intervals are indicated on the graph.

a State schools (base n=575)



b Independent schools (base n = 259)

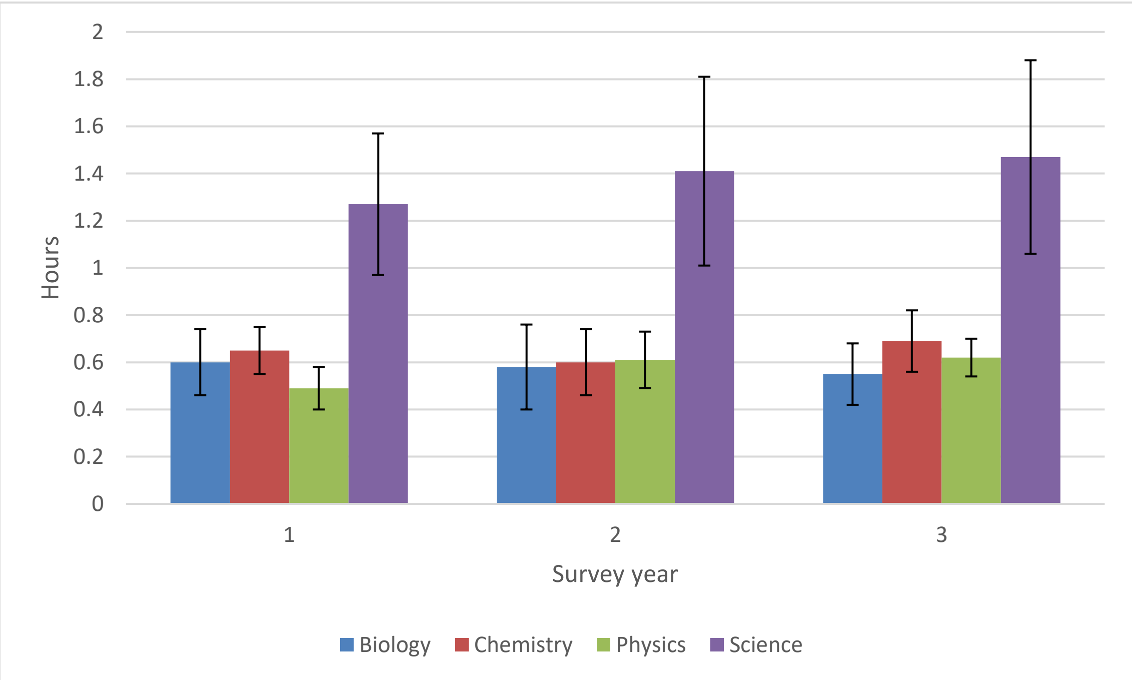
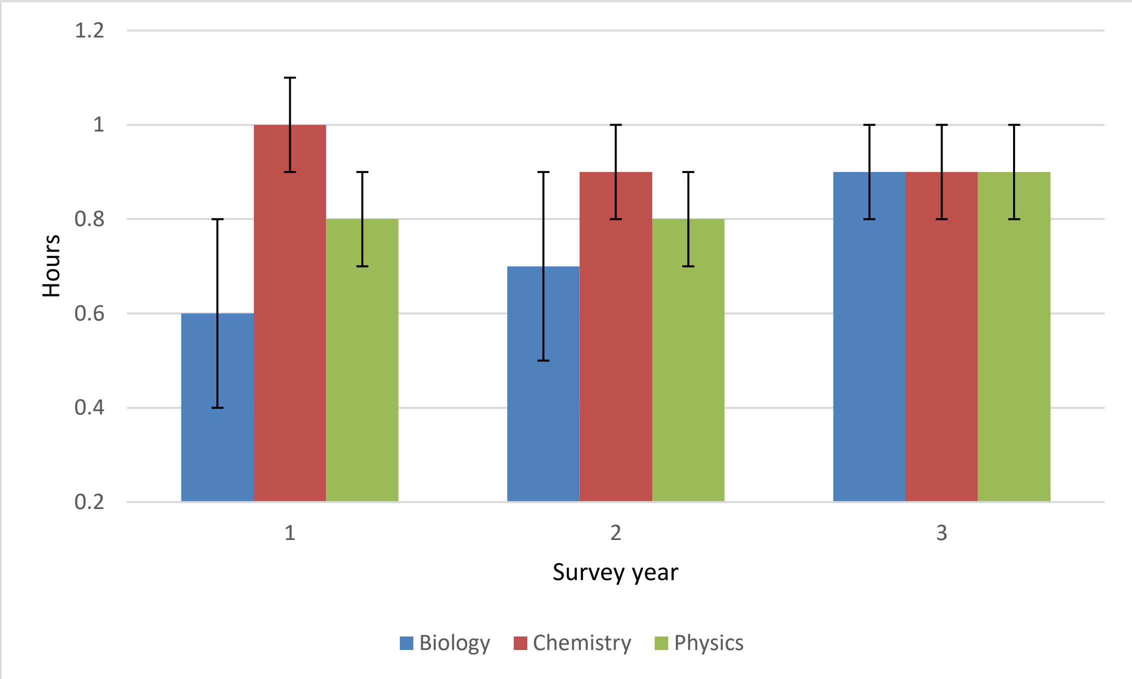


Figure 7. 14 – 16 age range (England): Bar chart comparing the average science lesson time spent on practical work per week (in hours) over the three survey years and between subjects. Respondents were heads of science and science teachers. 95% confidence intervals are indicated on the graph.

a State schools (base n = 915)



b Independent schools (base n = 467)

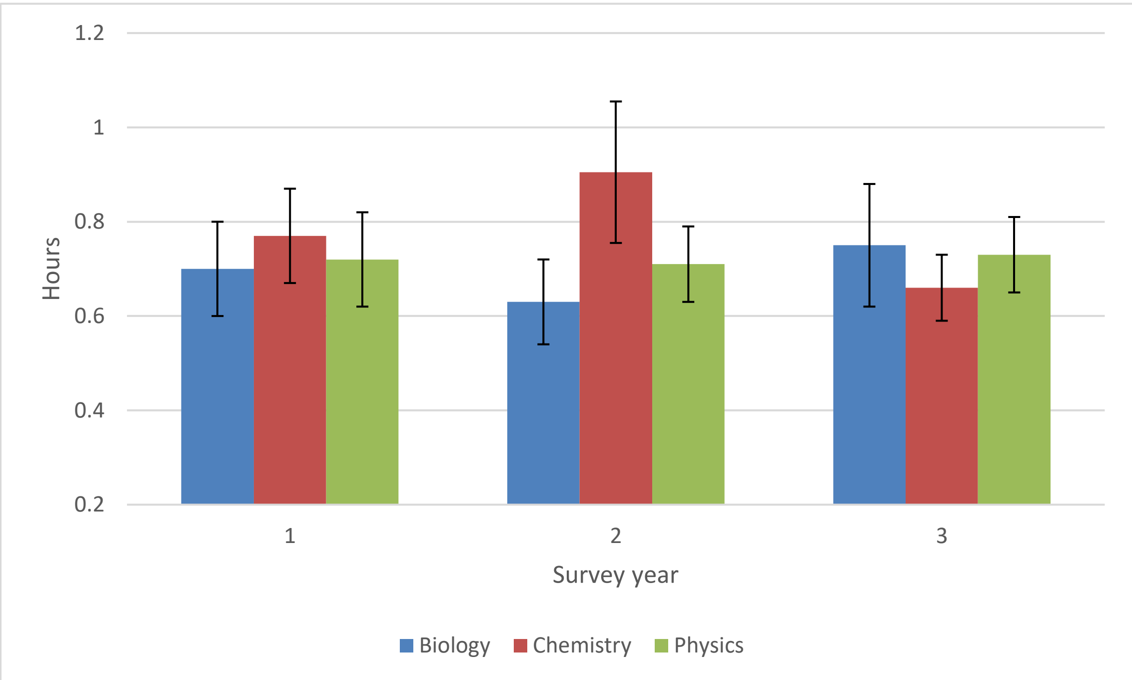
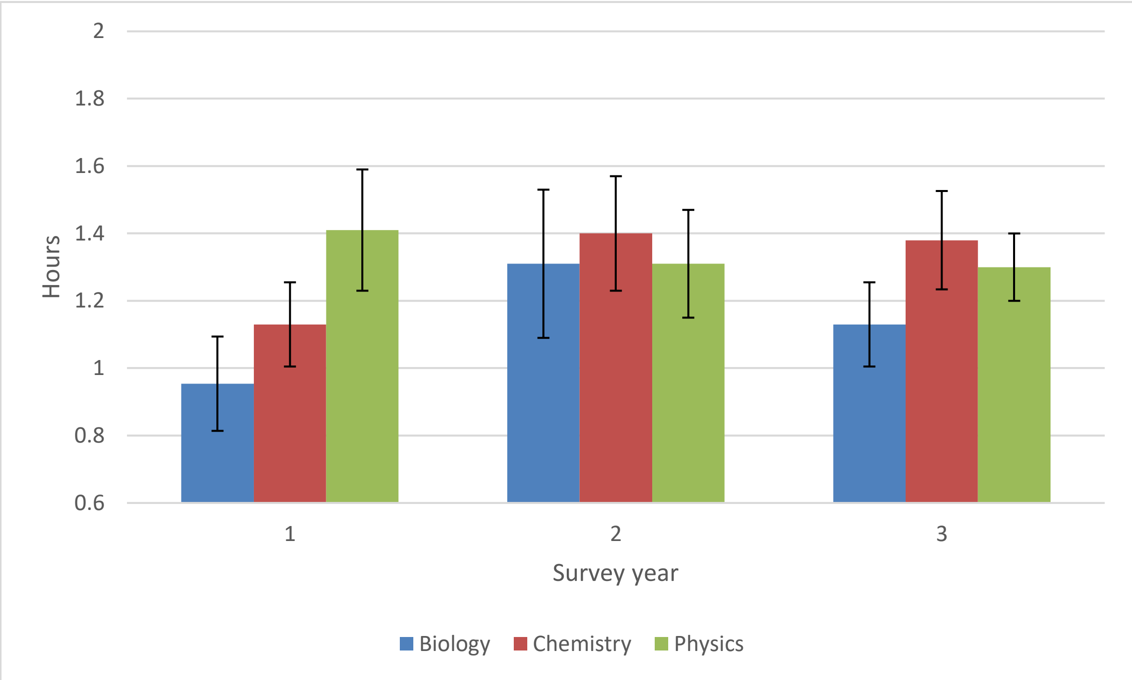


Figure 8. Post – 16 age range (England): Bar chart comparing the average science lesson time spent on practical work per week (in hours) over the three survey years and between subjects. Respondents were heads of science and science teachers. 95% confidence intervals are indicated on the graph.

a State schools (base n= 806)



b Independent schools (base n = 474)

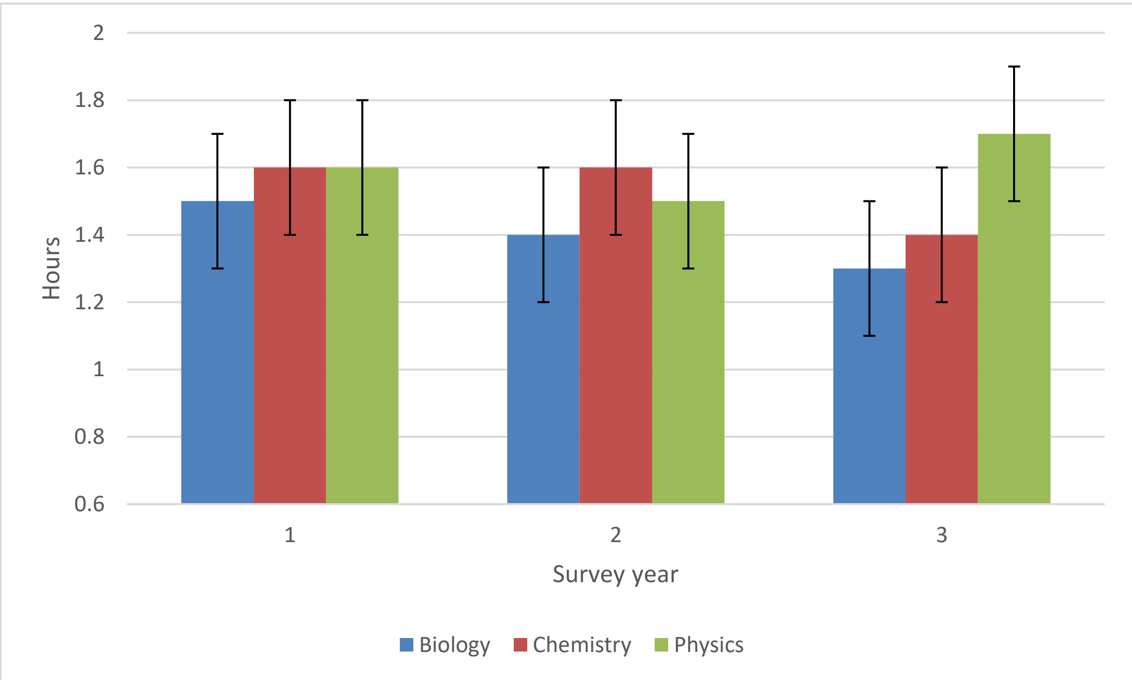
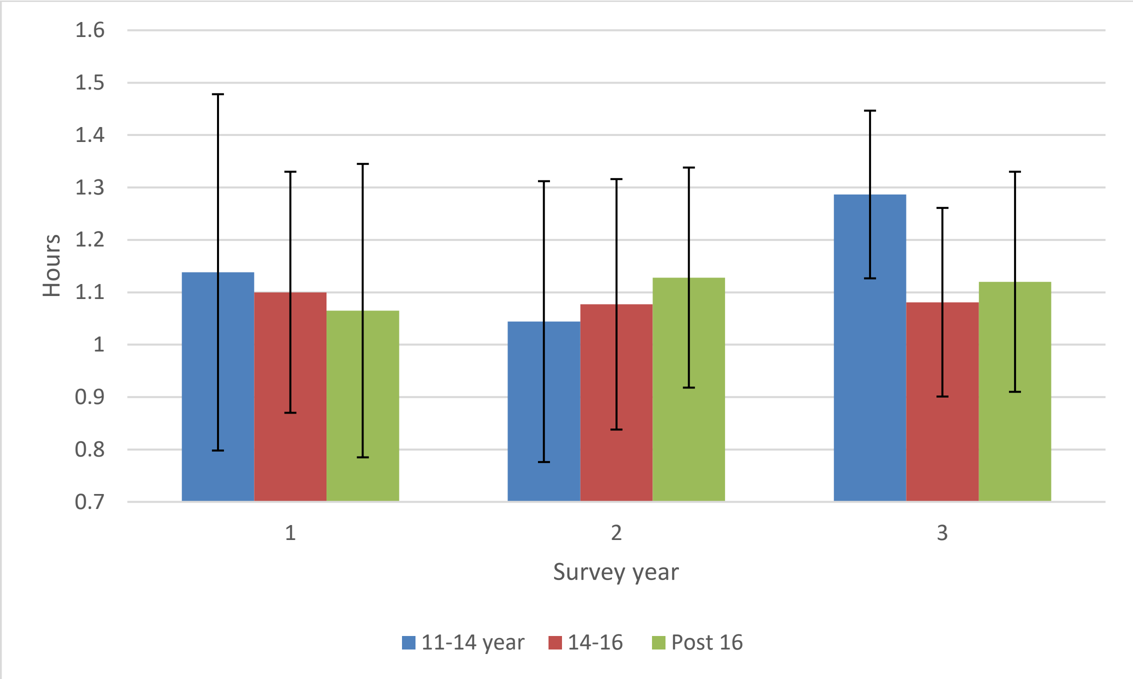


Figure 9. All subjects combined (Scotland): Bar chart comparing the average science lesson time spent on practical work per week (in hours) over the three survey years showing data for 11 – 14 age range (n = 91), 14 – 16 age range (n = 126) and post – 16 age range (n = 138). Respondents were heads of science and science teachers. 95% confidence intervals are indicated on the graph.



8.1.1.3 Number of practical work activities

Figure 10 to Figure 13 (and Table 9 in Appendix 3 to Table 12 in Appendix 3) show the number of practical work activities that heads of science and science teachers reported that their students carry out during an academic year for each individual subject in each of the three age ranges and across the three years of the study.

The findings show that in both state and independent schools in the 11 – 14 age range in all three years of the study, there was no difference in the number of practical work activities reported to be carried out by students in an academic year between biology, chemistry and physics. A higher number of practical work activities were carried out in science (as a subject) than in any of biology, chemistry and physics in year 2 of the study in state schools and in years 1 and 2 of the study in independent schools.

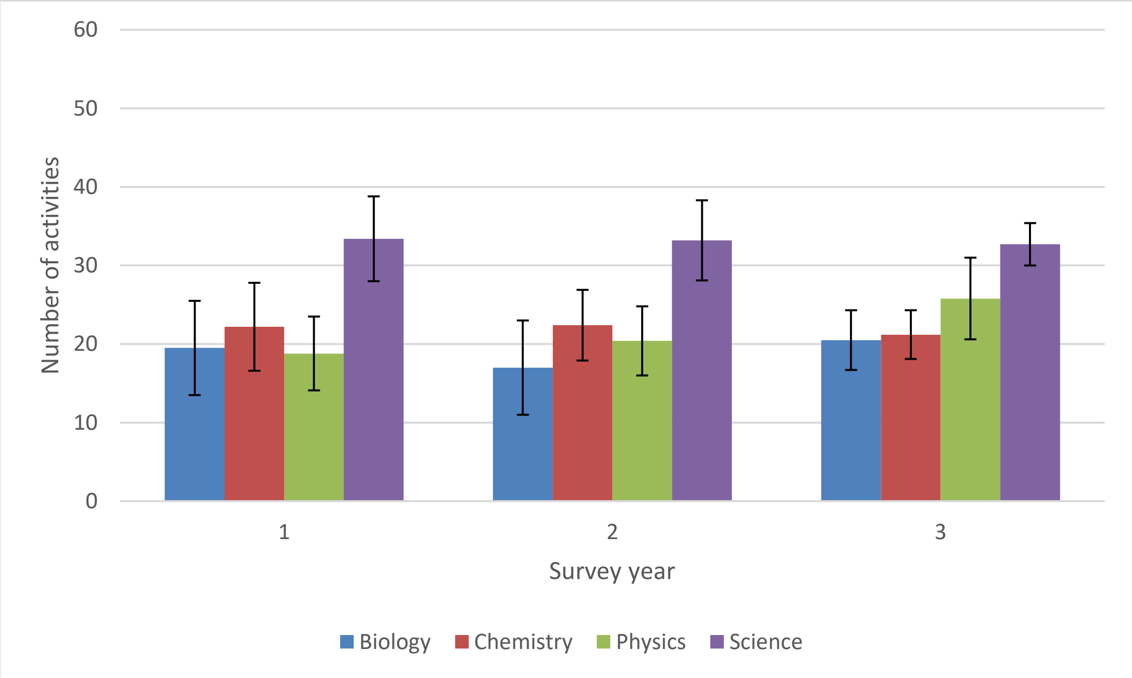
In the 14 – 16 age range in year 1 of the study, biology students carried out fewer practical work activities than chemistry students (eight less practical work activities in state schools and six less in independent schools). However, the number of practical work activities carried out by biology students in an academic year in state schools showed an increase over the course of the study.

In the post – 16 age range in year 1 of the study in both state and independent schools, biology students carried out fewer practical work activities than chemistry students (10 less in state schools and eight less in independent schools). On average, post – 16 biology students also carried out eight fewer practical work activities than physics students in state schools in year 1 of the study. A decrease was observed in the number of practical work activities carried out by students in an academic year in chemistry in both state and independent schools over the three years of the study.

Due to the lower response rate in Scotland, it is not possible to provide a breakdown of the findings at the level of individual subjects. Averaging all subjects together for each of the age ranges, shows that there is no statistically significant change over time in the number of practical work activities carried out by a student in an academic year in any of the age ranges.

Figure 10. **11 – 14 age range (England): Bar chart comparing the number of practical work activities undertaken by a student in an academic year over the three survey years and between subjects. Respondents were heads of science and science teachers teaching students. 95% confidence intervals are indicated on the graph.**

a State schools (base n= 565)



b Independent schools (base n = 262)

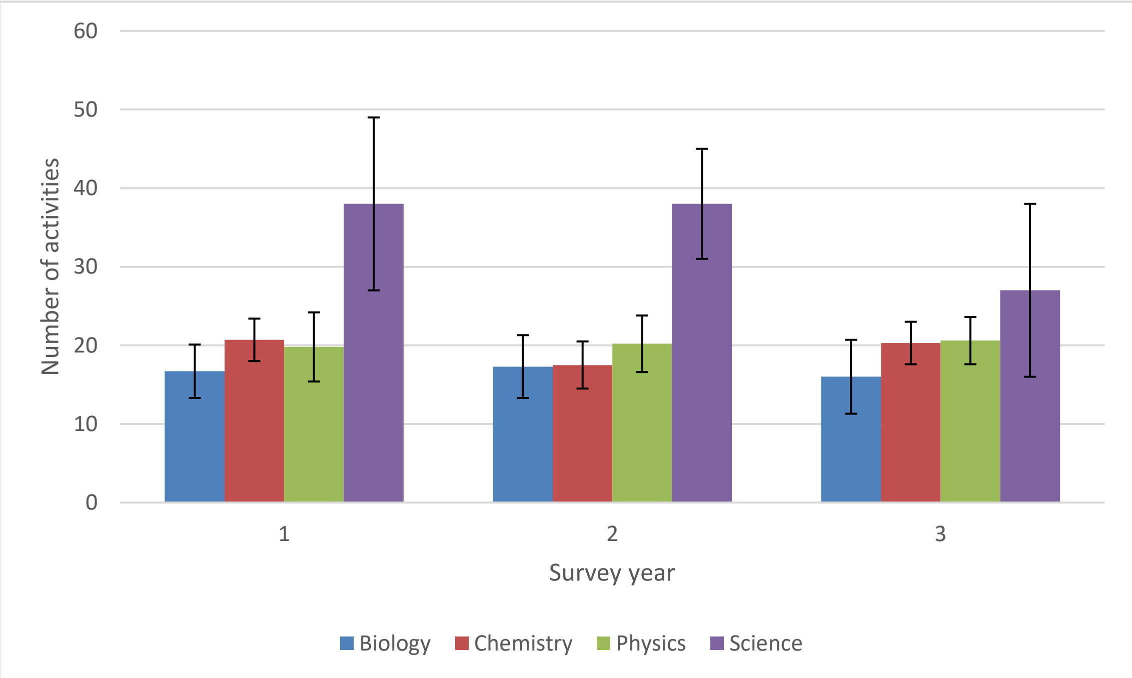
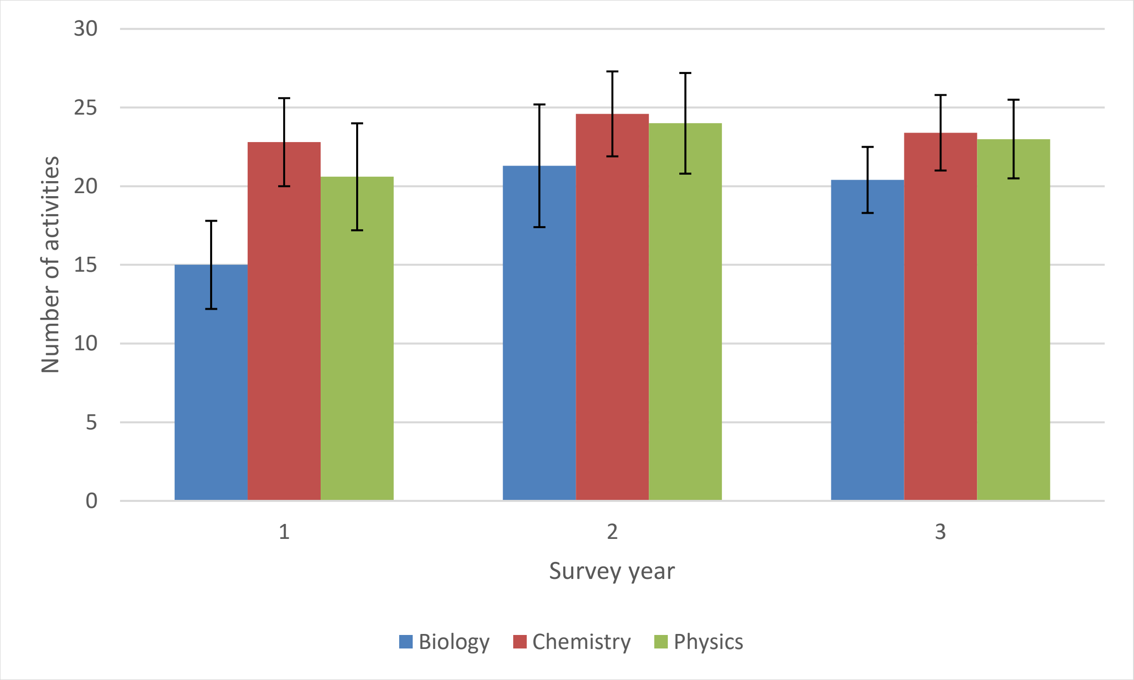


Figure 11. 14 – 16 age range (England): Bar chart comparing the number of practical work activities undertaken by a student in an academic year over the three survey years and between subjects. Respondents were heads of science and science teachers teaching students. 95% confidence intervals are indicated on the graph.

a State schools (base n= 890)



b Independent schools (base n = 460)

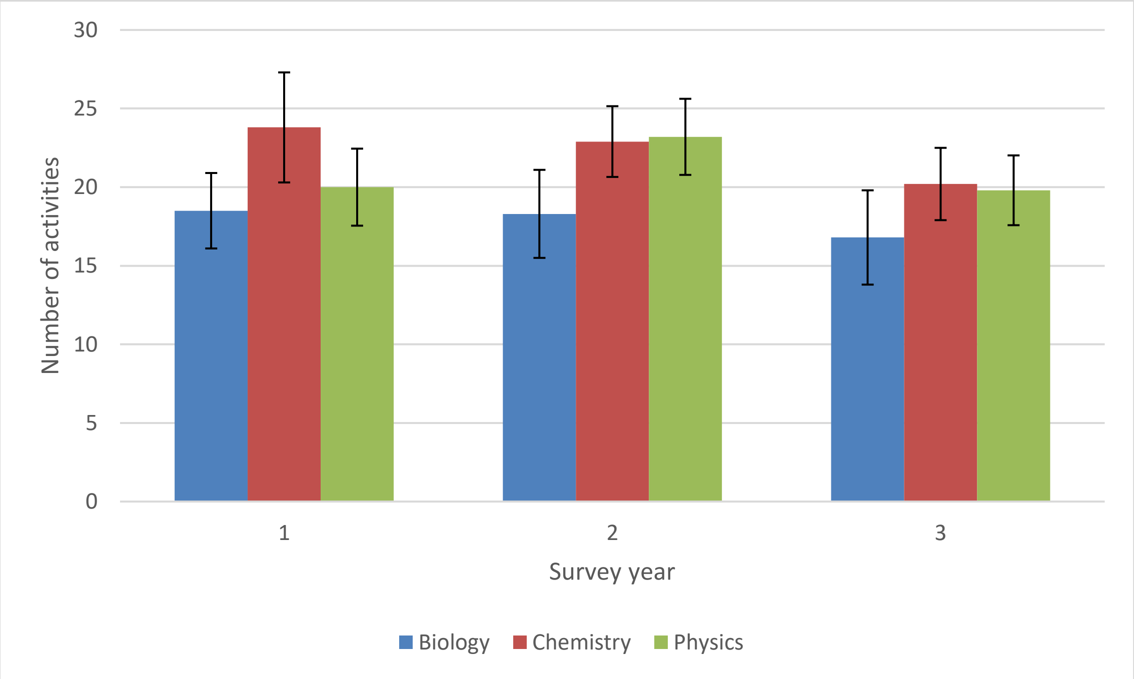
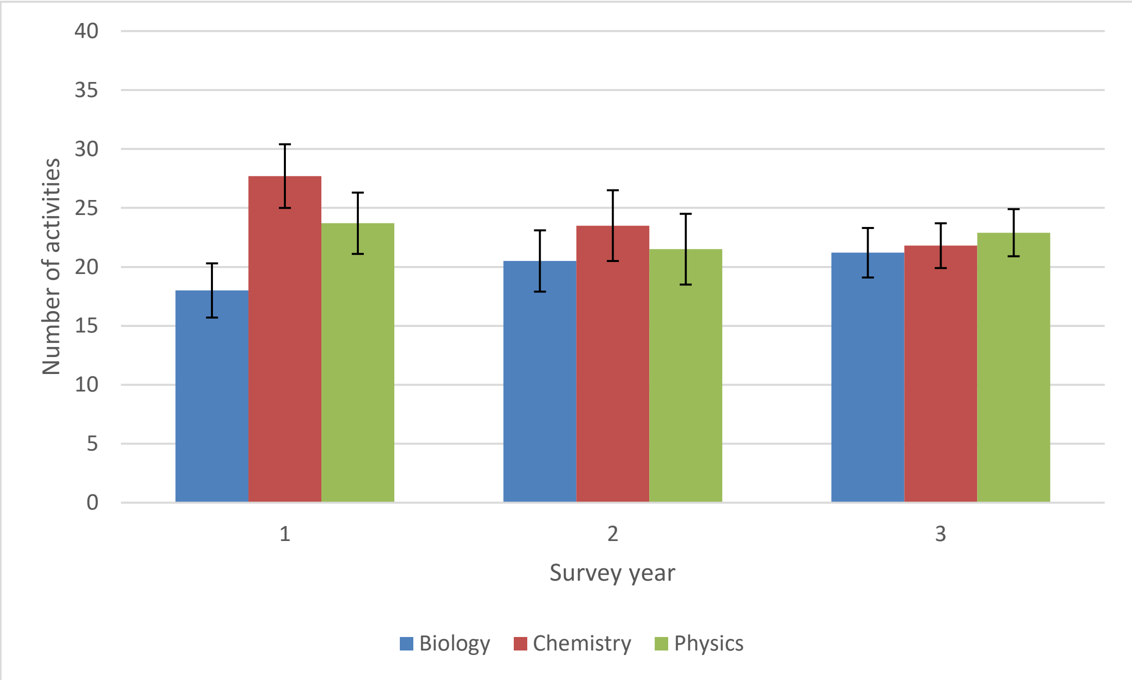


Figure 12. Post – 16 age range (England): Bar chart comparing the number of practical work activities undertaken by a student in an academic year over the three survey years and between subjects. Respondents were heads of science and science teachers teaching students. 95% confidence intervals are indicated on the graph.

a State schools (base n= 801)



b Independent schools (base n = 466)

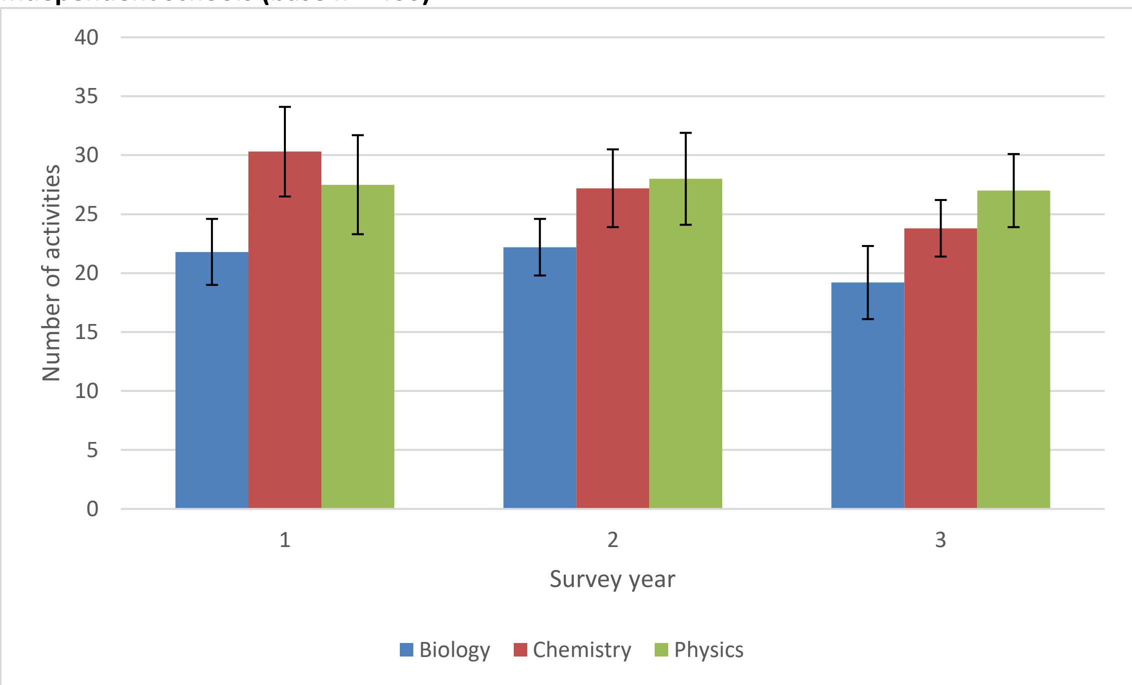
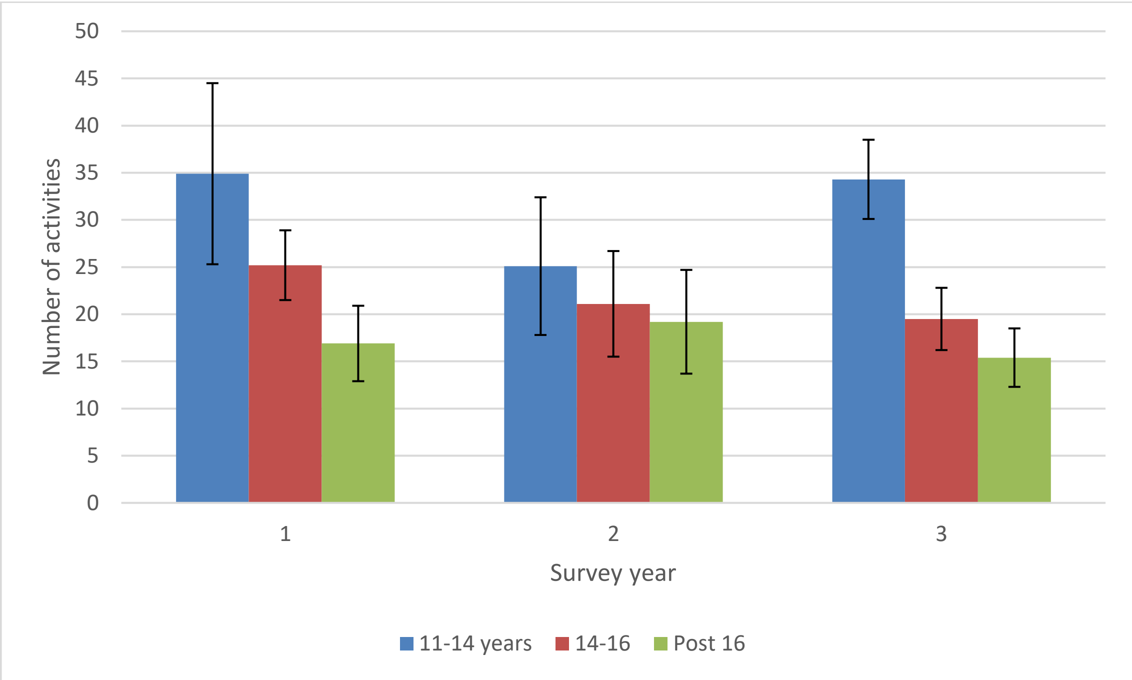


Figure 13. All subjects combined (Scotland): Bar chart comparing the number of practical work activities undertaken by a student in an academic year over the three survey years showing data for 11 – 14 age range (n = 79), 14 – 16 age range (n = 112) and post – 16 age range (n = 123). Respondents were heads of science and science teachers. 95% confidence intervals are indicated on the graph.



Qualitative data from focus group interviews with heads of science, teachers and technicians (England) indicated that integration of practical work into the GCSE and A level courses as a whole had improved with the introduction of the new curriculum. There was a perception that the introduction of the recommended practical activities in the new curriculum was leading all teachers to place a focus on practical work.

Example – Changes to practical work

A level - Mixed, non-selective, state school

In the first year of the study (before the changes to the A level curriculum) staff in the school expressed frustration that practical work was not well integrated into the A level curriculum, but was instead used as a standalone activity to teach a specific skill or as an examined activity.

> *"It became like a two-tier system. You did a simple practical for learning the key skill and then you had your assessment practical which was a mini exam. Because it worked towards 20% of the mark, the students were very focused on [the assessed practical] and everything else became a preparation for this big test and I think the downside with that was that everything else got relegated down to another experiment compared to this big experiment which goes towards your final mark. I think that is a shame because the key thing is that everything needs to be brought up, every experiment is important, everything is learning towards your key skills that you will be developing throughout the course."*

In year 2, the staff were pleased with the changes to the curriculum, reporting that practical work had become more integrated to the course.

> *"Rather than just a two-week panic at coursework time, [practical work] is a distinct and integral part of the course."*

By year 3, the college had moved to practical work gaining higher status within the course and having an emphasis on research, not just skills.

> *"I always thought practical work was important but having now gone through the first year with a new A level spec I now see how important it is. It has very much moved into the exam, so whilst I would teach it as a support for the subject, now I teach it as an individual subject within physics."*

> *"There is a bigger emphasis on research, whereas before we wouldn't necessarily have done an assessed practical on research and now we actually focus on it and students have to research their own method and then produce a full report with a reference list."*

Discussion in the focus groups identified that in the majority of schools, timetabling of lessons was conducive to practical work. However, timetabling within schools varied, with some schools reporting that teaching was split between different staff, which required careful planning to ensure that students had the opportunity to reflect on material between lessons a week apart, especially where there had only just been enough time to fit in the practical work within a lesson. Staff in schools with longer lessons (e.g. double periods) used practical work to split up the lessons, and where timetabling allowed, staff used single lessons to cover theory from practical work covered in double lessons. Some schools had changed their timetabling, dedicating whole mornings or afternoons to a single subject. Some staff commented that the level of content within the syllabus led to significant pressure on time within science lessons to fit in the required content, sometimes to the detriment of practical work.

Example – Changes to practical work and impact to content at GCSE and A Level

Boys, selective, state school

Across the period of the study, staff at the school commented about pressure from the quantity of material in the GCSE and A Level specifications impacting on the quantity and type of practical work.

In year 1 of the study

> *"In an ideal world I would have at least another period with my sixth form that I could have time to do practicals … buying equipment isn't a problem but in terms of the time constraints and the time with the boys we are so constrained in the length of the syllabus that we…that is the major problem of doing the practicals. (Q: And how long are your lessons?) I have a double and a single so 35 and 40 minutes, so the double is usually a 35 and 40 minute together and the single is a 35 or 40 minute period. It is not that you can't do the practicals within that period of time, the double period; it is the fact that you have so much syllabus to get through."*

In year 2 of the study (as staff knew the detail of the changes to the GCSE curriculum) they commented that there was little change in the content and that the main change for the school would be in restricting where content was taught within the course.

> *"The GCSE isn't that different in terms of content but we have had to reorganise it in order to put the stuff for further chemistry into year 11s so that we have completed the core combined science by the end of year 10. So content wise there is not a great change but order-wise yes some reorganisation has to take place with the new specification."*

In year 3 of the study, staff were still concerned at the level of content that had to be covered and the impact that this was having on the amount and type of practical work that could be included within lessons.

> *"It means you can't put in these nice little practicals that help with that grounding that people [in the focus groups] were talking about. You have to think if I do that then I can't cover that content because there is too much to squeeze in."*

8.1.2 Science lesson activities

This section considers the types of activity undertaken within science lessons and the method by which students work in the classroom. Changes to the types of activities carried out in science lessons and the ways students work have been considered by asking heads of science and science teachers: how much lesson time is spent on teacher demonstrations and computer simulations as well as hands on practical work; the frequency with which their students work as individuals, in pairs or in groups; tasks undertaken by students within practical work activities; opportunities for students to carry out open-ended, extended investigations; and opportunities for outdoor practical work.

Key findings:

Heads of science and science teachers were asked to report on how science lessons were divided between practical work, teacher demonstrations and using computer simulations.

Proportion of science lesson time spent on practical work

Age range	England state schools	England independent schools	Scotland state schools
Proportion of science lesson time spent on practical work, %			
11 – 14	32.9 (31.5, 34.3)	40.1 (37.7, 42.5)	41.1 (37.6, 44.7)
14 – 16	27.3 (26.3, 28.3)	30.4 (29.2, 31.6)	27.9 (24.8, 31.0)
Post – 16	26.5 (25.6, 27.4)	30.1 (28.9, 31.3)	24.8 (21.7, 27.9)

Proportion of science lesson time spent on practical work per week	
11 – 14 age range	↑Chemistry (England – Independent) ↑Physics (England – Independent) ↑Science (England – State)
14 – 16 age range	↑Biology (England – State)
Post – 16 age range	↓Biology (England – Independent)

For state schools in England, the correlation between the proportion of science lesson time per week spent on practical work and deprivation measures were calculated. In year 1 of the study in the 11 – 14 and 14 – 16 age ranges, a negative correlation was observed between IDACI score and the proportion of practical work carried out per week, indicating that the higher the level of deprivation of the school, the lower the proportion of lesson time each week spent on practical work.

There was no correlation observed between the proportion of lesson time spent on practical work and the percentage of free school meal uptake in any age range in all three years of the study for state schools in England.

Proportion of time spent on teacher demonstrations and computer simulations

Across all age ranges in England and Scotland, using computer simulations was the activity for which respondents reported spending the lowest proportion of lesson time per week, compared to practical work and teacher demonstrations. In state schools in the 14 – 16 age range, an increase in the use of computer simulations was observed for biology over the course of the study. A decrease in the use of computer simulations was observed in chemistry for state schools in England in the post – 16 age range.

Teacher demonstrations were reported to be used in less than 21% of lesson time per week in England and Scotland. In independent schools in the 11 – 14 age range, a statistically significant increase in the proportion of lesson time spent carrying out teacher demonstrations in chemistry was observed over the course of the study.

Method of working

In the 11 – 14 and 14 – 16 age ranges in all three years of the study, over 80% of respondents from state schools in England and over 90% of respondents from independent schools reported that their students worked in pairs half of the time or more when carrying out practical work activities in biology, chemistry and physics.

In state schools in the post – 16 age range over 75% of respondents indicated that their students worked in pairs half of the time or more. In independent schools, over 50% of respondents teaching biology and chemistry indicated that their students worked in pairs half of the time or more. The value was higher in physics, where over 75% of respondents indicated that their students worked in pairs half the time or more.

Less than 30% of respondents from state and independent schools in the 11 – 14 and 14 – 16 age ranges reported that their students had the opportunity to work as individuals half or most of the time in biology, chemistry and physics or science. In the post – 16 age range more than 35% of respondents from state schools and more than 58% of respondents from independent schools reported that their students worked as individuals half of the time or more.

Tasks undertaken within practical work activities

In England and Scotland in all years of the study, following prepared instructions was the most common task which students undertook within practical work activities. In state and independent schools in England, analysing data was the next most common task, other than in the post -16 age range in biology, where following prepared instructions and analysis data were carried out at the same frequency, and in physics in the post – 16 age range, where analysing data took place more frequently than following prepared instructions.

No systematic changes over the course of the study were observed in the tasks staff reported students undertook in practical work activities (e.g. for all subjects within an age range). However, a decrease in how often students carried out open-ended practical work, or evaluated experiments as part of their practical work activities, was observed in chemistry in state schools in the 11 – 14 age range. An increase in the frequency of students evaluating experiments as part of their practical work activities was observed in physics in the 14 – 16 age range in state schools. A decrease in how often students analysed data as part of their practical work activities was observed in biology in independent schools in the 14 – 16 age range.

In the post -16 age range in state schools, all subjects showed a reported an increase over the period of the study in how often students evaluated experiments as part of their practical work activities. An increase in how often chemistry students in state schools carried out open-ended practical work was also noted.

In all age ranges and subjects, respondents indicated that their students carried out open-ended activities (which included designing their own method and proposing a hypothesis) in ‘a few to half’ of practical work activities. When asked about open-ended, extended investigations (longer than two weeks) in year 3 of the study, less than 25% of respondents in each age range and subject indicated that their students had had the opportunity to carry out this type of task, other than in physics in the post – 16 age range in state schools in England and post – 16 students in Scotland. Eighty-five percent of staff teaching post – 16 physics students in state schools in England reported that their students had had an opportunity to carry out an open-ended, extended investigation. In Scotland, 70% of staff reported their post – 16 students had had the opportunity to carry out open-ended, extended investigation (longer than 2 weeks) involving practical work in lesson time in the last academic year.

Across all age ranges and subjects in all three years of the study, respondents teaching in state schools reported that on average students spent less than 1.5 days per year on outdoor practical work. The exception to this was for biology students in the post – 16 age range who spent over 2 days on outdoor practical work. Responses from qualitative interviews and focus groups identified this time as being spent on residential fieldwork.

8.1.2.1 *Science lesson activities*

Heads of science and science teachers were asked to report on how science lessons were divided between practical work, teacher demonstrations and using computer simulations. Respondents were asked to report the number of hours per week spent on each activity during science lesson time. Data were excluded if a respondent did not include a response for the total science lesson time, or the total value when summing the individual activities was greater than the total lesson time. Six percent of responses in the 11 – 14 age range, 4% in the 14 – 16 age range and 2% in the post – 16 age range were excluded due to the total time for individual activities summing to greater than total lesson time.

Table 9 to Table 12 below show the breakdown by proportion of science lesson time per week on the three activities for individual subjects in each of the three age ranges and across the three years of the study. It is important to consider these findings in the context of total science lesson time as a change in the proportion of science lesson time may be driven by a change in the total lesson time and/or a change in the time spent on activities within the lessons.

<u>11 – 14 age range</u>

The findings show that in state schools in England in the 11 – 14 age range, the proportion of lesson time spent on practical work increased in science (as a subject) in state schools over the three years of the study (Table 9). However, despite this, there was no difference in the proportion of science lesson time spent on practical work between biology, chemistry, physics and science in any of the three years.

In independent schools in the 11 – 14 age range, science (as a subject) spent a higher proportion of lesson time on practical work than biology (53% of lesson time in science compared to 36% of lesson time in biology). The proportion of science lesson time spent on practical work increased in both chemistry and physics over the three years of the study.

State schools spent a higher proportion of lesson time on practical work compared to independent schools in chemistry in year 1 of the study (30% compared to 14%). However, in year 3 of the study, independent schools spent 41% compared to 31% of lesson time in state schools on practical work. and 3 of the study and science in year 2 of the study. In science in year 2 of the study, respondents from independent schools reported spending 53% of lesson time per week in science on practical work compared to 34% in state schools.

In the 11 – 14 age range in both state and independent schools (Table 9), respondents indicated that the activity they spent least time on was using computer simulations (less than 6% of lesson time in all subjects and years of the study). Independent schools spent less time than state schools conducting teacher demonstrations in chemistry in year 1 of the study (3% of lesson time in independent schools compared to 16% in state schools). However, an increase in the proportion of lesson time spent carrying out teacher demonstrations was observed in chemistry in independent schools over the course of the study.

<u>14 – 16 age range</u>

In year 1 of the study in state schools in England, biology students spent a lower proportion of lesson time on practical work than chemistry and physics students (19% of lesson time in biology compared to 29% in chemistry and 27% in physics) (Table 10). In year 2, biology was again lower than chemistry with biology students spending 23% of lesson time on practical work compared to 30% in chemistry. However, biology showed an increase in the proportion of science lesson time spent on practical work over the three years of the study. In independent schools in year 2 of the study biology students spent a lower proportion of lesson time on practical work than chemistry students (27% of lesson time compared to 36% in chemistry).

Respondents from independent schools reported spending a higher proportion of lesson time on practical work in biology in than state schools in England (26% of lesson time in independent schools compared to 19% in state schools).

In state schools in England in year 2 of the study, physics students spent a higher proportion of lesson time on teacher demonstrations than biology and chemistry students (20% of lesson time in physics compared to 8% in biology and 11% in chemistry). In year 3 of the study, physics students spent 16% of science lesson time per week on teacher demonstrations compared to 9% in biology.

In the 14 - 16 age range in both state and independent schools, respondents indicated that the activity they spent least time on was using computer simulations. Physics students in state schools in England also spent a higher proportion of lesson time using computer simulations than biology students in year 1 of the study (7% of lesson time in physics compared to 3% in biology). An increase in the use of computer simulations was observed for biology in state schools in England over the course of the study. In independent schools, physics students spent a higher proportion of lesson time on computer simulations than chemistry students in year 3 of the study (7% physics compared to 3% in chemistry).

Post – 16 age range

In state schools in the post – 16 age range in year 1 of the study, the proportion of science lesson time spent on practical work in biology was less than chemistry and physics (19% of science lesson time in biology compared to 27% in chemistry and 31% in physics) (Table 11). In independent schools in the post – 16 range in year 3 of the study, biology students spent a lower proportion of lesson time on practical work than physics students (24% of lesson time in biology compared to 33% in physics). The proportion of science lesson time spent on practical work in biology decreased over the three years of the study in independent schools. Biology students in independent schools in year 1 of the study spent a higher proportion of lesson time on practical work than state school students (30% of science lesson time in independent schools compared to 19% in state schools). In physics in year 3 of the study, independent schools students spent 33% of science lesson time per week on practical work compared to 27% for state school students.

In both state and independent schools in England, physics students spent a higher proportion of lesson time observing teacher demonstrations than biology and chemistry students at various points in the study. In state schools in England, 15% of lesson time in physics in year 2 of the study was spent on teacher demonstrations compared to 7% in chemistry. In year 3 of the study, 13% of lesson time in physics was spent on teacher demonstrations compared to 9% in chemistry. In independent schools in year 1 of the study, 17% of lesson time in physics was spent on teacher demonstrations compared to 10% in chemistry. In year 2 of the study, physics students spent 17% of lesson time per week on teacher demonstrations compared to 9% in both biology and chemistry. In year 3 of the study, physics students spent 15% of lesson time per week on teacher demonstrations compared to 9% in biology.

Respondents from both state and independent schools in the post – 16 age range indicated that the activity they spent least time on was using computer simulations. In both state and independent schools in England, physics students spent a higher proportion of lesson time using computer simulations than chemistry students. In state schools in England, a statistically significant decrease in the reported use of computer simulations was observed for chemistry over the course of the study.

Scotland

There was no change over time in the proportion of science lesson time spent on practical work in any of the age ranges in Scotland (Table 12). Respondents indicated that the activity they spent least time on was using computer simulations. Students in 11 – 14 age range were reported to spend a higher proportion of lesson time observing teacher demonstrations than in the post – 16 age range (21% of lesson time in the 11 – 14 age range compared to 10% in the post – 16 age range).

Table 9. 11 – 14 age range (England): Percentage of science lesson time spent on practical work, teacher demonstrations and computer simulation over the three survey years and by subject. Respondents were heads of science and science teachers teaching students. 95% confidence intervals are indicated in brackets. Statistically significant rates of change per year are highlighted in bold with the level of significance stated below the table.

11 – 14		Year 1		Year 2		Year 3	Rate of change per year
	n	Value	n	Value	n	Value	
State schools							
Biology							
Practical work (%)	15	22 (31, 13)	16	28 (35, 21)	43	27 (32, 22)	1.7
Practical work (hrs)	17	0.8 (1.0, 0.6)	16	0.6 (0.8, 0.4)	43	0.7 (0.8, 0.6)	-0.033
Teacher demo (%)	15	19 (27, 11)	16	13 (20, 6)	43	19 (24, 14)	0.8
Simulations (%)	15	2 (6, 0)	16	2 (4, 0)	43	5 (8, 2)	1.4
Chemistry							
Practical work (%)	19	21 (31, 11)	32	32 (36, 26)	62	31 (35, 27)	3.8
Practical work (hrs)	23	0.9 (1.2, 0.8)	33	0.8 (1.0, 0.6)	62	0.8 (1.0, 0.6)	-0.063
Teacher demo (%)	19	16 (20, 12)	32	17 (22, 12)	62	17 (20, 14)	-0.1
Simulations (%)	19	2 (4, 0)	32	6 (9, 3)	62	5 (7, 3)	0.7
Physics							
Practical work (%)	15	27 (37, 17)	30	34 (40, 28)	42	34 (39, 29)	2.6
Practical work (hrs)	18	0.7 (0.9, 0.5)	30	0.7 (0.9, 0.5)	42	0.9 (1.1, 0.7)	0.142
Teacher demo (%)	15	14 (21, 7)	30	21 (26, 16)	42	19 (22, 16)	1.7
Simulations (%)	15	4 (8, 0)	30	8 (12, 4)	42	5 (7, 3)	0.1
Science							
Practical work (%)	48	28 (33, 23)	71	34 (38, 30)	165	34 (37, 31)	**2.6***
Practical work (hrs)	57	1.1 (1.3, 0.9)	71	1.2 (1.4, 1.0)	165	1.1 (1.2, 1.0)	-0.045
Teacher demo (%)	48	12 (15, 9)	71	18 (21, 15)	165	17 (19, 15)	1.6
Simulations (%)	48	5 (7, 3)	71	3 (4, 2)	165	5 (7, 3)	1.6
Independent schools							
Biology							
Practical work (%)	14	17 (30, 4)	18	36 (44, 28)	20	32 (41, 23)	6.8
Practical work (hrs)	17	0.6 (0.7, 0.5)	18	0.6 (0.8, 0.4)	20	0.6 (0.7, 0.5)	-0.026
Teacher demo (%)	14	7 (14, 0)	18	16 (21, 11)	20	16 (21, 11)	3.8
Simulations (%)	14	4 (8, 0)	18	4 (7, 1)	20	4 (7, 1)	-0.6
Chemistry							
Practical work (%)	26	14 (18, 10)	20	41 (35, 47)	32	41 (36, 46)	**13.1***
Practical work (hrs)	32	0.7 (0.8, 0.6)	20	0.6 (0.7, 0.5)	32	0.7 (0.8, 0.6)	0.018
Teacher demo (%)	26	3 (5, 1)	20	20 (25, 15)	32	21 (26, 16)	**8.8***
Simulations (%)	26	1 (2, 0)	20	2 (3, 1)	32	4 (6, 2)	1.3
Physics							
Practical work (%)	13	19 (29, 9)	21	39 (47, 31)	39	43 (49, 37)	**10.7***
Practical work (hrs)	20	0.5 (0.6, 0.4)	21	0.6 (0.7, 0.5)	39	0.6 (0.7, 0.5)	0.142
Teacher demo (%)	13	9 (14, 4)	21	23 (29, 17)	39	17 (21, 13)	2.1
Simulations (%)	13	4 (8, 0)	21	4 (6, 2)	39	6 (8, 4)	1.5
Science							
Practical work (%)	-	-	14	53 (47, 59)	11	43 (56, 30)	-9.1
Practical work (hrs)	15	1.3 (1.6, 1.0)	14	1.4 (1.8, 1.0)	11	1.4 (1.8, 1.0)	0.078
Teacher demo (%)	-	-	14	15 (20, 10)	11	12 (16, 8)	3.4
Simulations (%)	-	-	14	6 (13, 0)	11	6 (11, 1)	1.9

$*P<0.05$

Table 10. 14 – 16 age range (England): Percentage of science lesson time spent on practical work, teacher demonstrations and computer simulation over the three survey years and by subject. Respondents were heads of science and science teachers teaching students. 95% confidence intervals are indicated in brackets. Statistically significant rates of change per year are highlighted in bold with the level of significance stated below the table.

14 – 16		Year 1		Year 2		Year 3	Rate of change per year
	n	Value	n	Value	n	Value	
State schools							
Biology							
Practical work (%)	54	19 (23, 15)	72	23 (26, 20)	142	26 (29, 23)	**3.0***
Practical work (hrs)	55	0.6 (0.8, 0.4)	73	0.7 (0.8, 0.6)	142	0.9 (1.0, 0.8)	**0.125***
Teacher demo (%)	54	13 (18, 8)	72	8 (11, 5)	142	9 (11, 7)	-1.6
Simulations (%)	54	3 (4, 2)	72	5 (7, 3)	142	6 (8, 4)	**1.7***
Chemistry							
Practical work (%)	81	29 (32, 26)	100	30 (33, 27)	166	30 (33, 27)	0.4
Practical work (hrs)	82	1.0 (1.1, 0.9)	100	0.9 (1.0, 0.8)	166	0.9 (1.0, 0.8)	-0.010
Teacher demo (%)	81	13 (16, 10)	100	11 (14, 8)	166	11 (13, 9)	-0.8
Simulations (%)	81	5 (7, 3)	100	5 (7, 3)	166	6 (8, 4)	0.6
Physics							
Practical work (%)	66	27 (30, 24)	69	29 (33, 25)	128	28 (31, 25)	0.7
Practical work (hrs)	67	0.8 (0.9, 0.7)	69	0.8 (0.9, 0.7)	128	0.8 (0.9, 0.7)	0.022
Teacher demo (%)	66	20 (25, 15)	69	20 (24, 16)	128	16 (19, 13)	-2.3
Simulations (%)	66	7 (9, 5)	69	5 (7, 3)	128	7 (9, 5)	0.5
Independent schools							
Biology							
Practical work (%)	32	26 (30, 24)	44	27 (30, 24)	43	27 (30, 24)	0.2
Practical work (hrs)	32	0.7 (0.8, 0.6)	44	0.6 (0.7, 0,5)	43	0.7 (0.8, 0.6)	0.017
Teacher demo (%)	32	17 (21, 13)	44	14 (17, 11)	43	13 (17, 9)	-2.1
Simulations (%)	32	6 (9, 3)	44	6 (9, 3)	43	6 (9, 3)	-0.1
Chemistry							
Practical work (%)	56	32 (36, 28)	50	36 (40, 32)	61	30 (33, 27)	-1.0
Practical work (hrs)	56	0.8 (0.9, 0.7)	51	0.9 (1.1, 0.7)	61	0.7 (0.8, 0.6)	-0.059
Teacher demo (%)	56	14 (17, 11)	50	18 (21, 15)	61	14 (17, 11)	0.4
Simulations (%)	56	4 (5, 3)	50	4 (6, 2)	61	3 (4, 2)	-0.3
Physics							
Practical work (%)	43	31 (35, 27)	54	31 (34, 28)	78	31 (33, 29)	0.2
Practical work (hrs)	43	0.9 (1.2, 0.6)	54	0.7 (0.8, 0.6)	79	0.7 (0.8, 0.6)	-7.9
Teacher demo (%)	43	20 (25, 15)	54	20 (24, 16)	78	20 (23, 17)	-0.4
Simulations (%)	43	5 (7, 3)	54	5 (7, 3)	78	7 (9, 5)	0.9

$^*P<0.05$

Table 11. Post – 16 age range (England): Percentage of science lesson time spent on practical work, teacher demonstrations and computer simulation over the three survey years and by subject. Respondents were heads of science and science teachers teaching students. 95% confidence intervals are indicated in brackets. Statistically significant rates of change per year are highlighted in bold with the level of significance stated below the table.

Post – 16		**Year 1**		**Year 2**		**Year 3**	**Rate of change per year**
	n	**Value**	**n**	**Value**	**n**	**Value**	
State schools							
Biology							
Practical work (%)	65	19 (22, 16)	82	25 (28, 22)	112	24 (26, 22)	1.7
Practical work (hrs)	65	1.0 (1.1, 0.9)	82	1.3 (1.5, 1.1)	112	1.1 (1.2, 1.0)	0.065
Teacher demo (%)	65	12 (16, 8)	82	9 (12, 6)	112	9 (12, 6)	-1.4
Simulations (%)	65	4 (6, 2)	82	4 (5, 3)	112	5 (7, 3)	0.5
Chemistry							
Practical work (%)	83	27 (30, 24)	86	27 (30, 24)	138	28 (30, 26)	0.5
Practical work (hrs)	83	1.3 (1.5, 1.1)	85	1.3 (1.4, 1.2)	138	1.4 (1.5, 1.3)	0.023
Teacher demo (%)	83	11 (13, 9)	86	7 (8, 6)	138	9 (10, 8)	-0.8
Simulations (%)	83	4 (6, 2)	86	2 (3, 1)	138	2 (3, 1)	**-0.9***
Physics							
Practical work (%)	65	31 (35, 27)	67	27 (30, 24)	109	27 (29, 25)	-1.7
Practical work (hrs)	65	1.5 (1.7, 1.3)	65	1.3 (1.5, 1.1)	109	1.3 (1.4, 1.2)	-0.049
Teacher demo (%)	65	15 (18, 12)	67	15 (18, 12)	109	13 (15, 11)	-0.7
Simulations (%)	65	6 (8, 4)	67	6 (7, 5)	109	6 (7, 5)	0.1
Independent schools							
Biology							
Practical work (%)	32	30 (35, 25)	41	29 (33, 25)	55	24 (27, 21)	**-3.1***
Practical work (hrs)	32	1.5 (1.7, 1.3)	41	1.4 (1.6, 1.2)	55	1.3 (1.5, 1.1)	-0.126
Teacher demo (%)	32	11 (16, 6)	41	9 (12, 6)	55	9 (11, 7)	-1.2
Simulations (%)	32	6 (8, 4)	41	5 (7, 3)	55	4 (6, 2)	-0.8
Chemistry							
Practical work (%)	56	31 (35, 26)	52	30 (33, 27)	59	28 (31, 25)	-1.3
Practical work (hrs)	56	1.6 (1.8, 1.4)	52	1.6 (1.8, 1.4)	59	1.4 (1.6, 1.2)	-0.090
Teacher demo (%)	56	10 (12, 8)	52	9 (11, 7)	59	13 (17, 9)	1.6
Simulations (%)	56	3 (4, 2)	52	2 (3, 1)	59	2 (3, 1)	-0.5
Physics							
Practical work (%)	42	30 (34, 26)	57	32 (35, 29)	79	33 (36, 30)	1.1
Practical work (hrs)	42	1.6 (1.8, 1.4)	57	1.5 (1.7, 1.3)	79	1.7 (1.9, 1.5)	0.090
Teacher demo (%)	42	17 (19, 15)	57	17 (20, 14)	79	15 (17, 13)	-1.0
Simulations (%)	42	5 (7, 3)	57	6 (8, 4)	79	7 (8, 6)	0.6

***P<0.05**

Table 12. All age ranges (Scotland): Percentage of science lesson time spent on practical work, teacher demonstrations and computer simulation over the three survey years and by subject. Respondents were heads of science and science teachers teaching students. 95% confidence intervals are indicated in brackets.

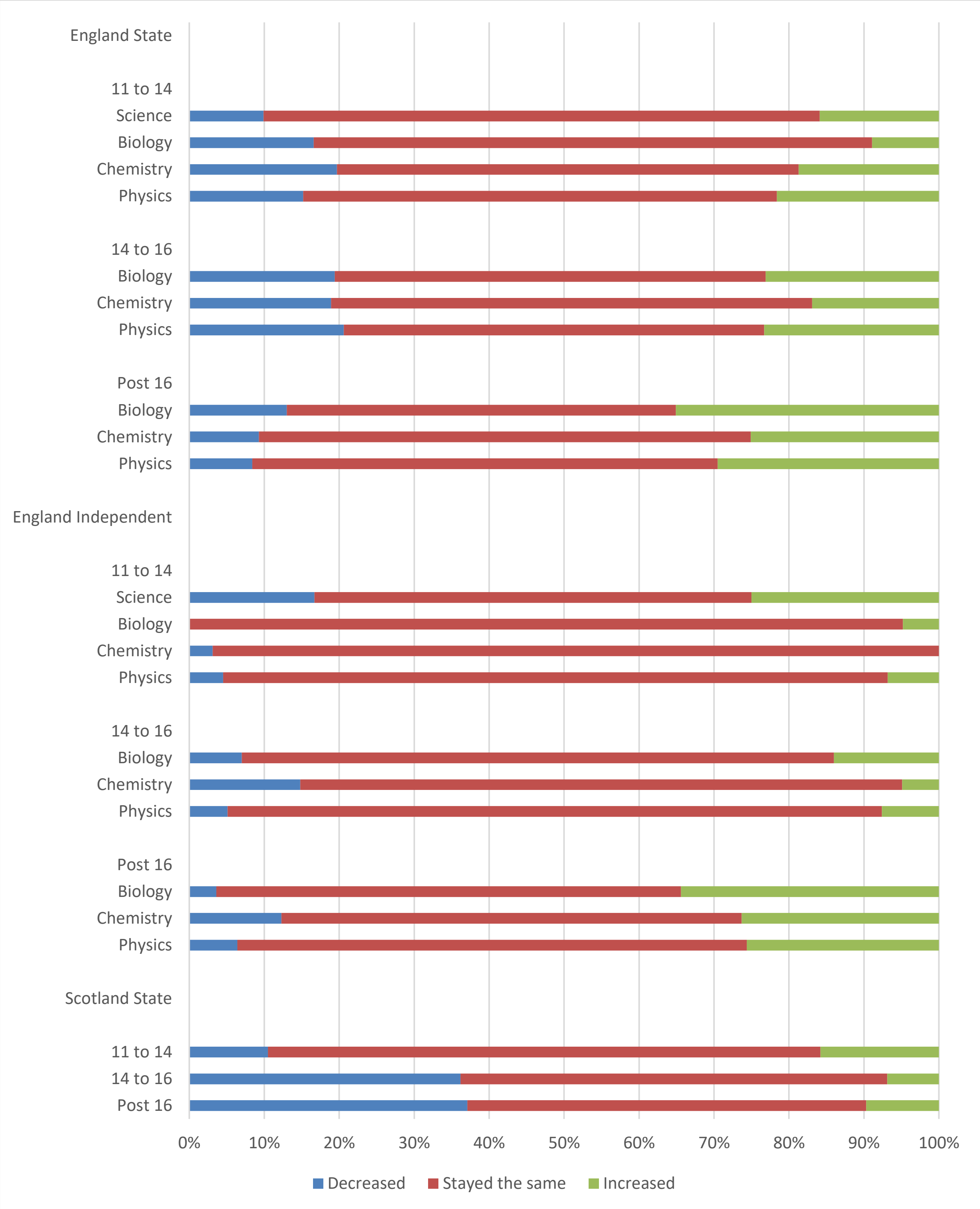
Scotland		**Year 1**		**Year 2**		**Year 3**	**Rate of change per year**
	n	**Value**	**n**	**Value**	**n**	**Value**	
State schools							
11 – 14							
Practical work (%)	-	-	18	41 (49, 33)	56	42 (46, 38)	0.8
Practical work (hrs)	13	1.1 (1.5, 0.7)	19	1.0 (1.2, 0.8)	56	1.2 (1.4, 1.0)	0.088
Teacher demo (%)	-	-	18	21 (27, 15)	56	17 (20, 14)	-2.8
Simulations (%)	-	-	18	5 (9, 1)	56	6 (8, 4)	1.3
14 – 16							
Practical work (%)	23	29 (35, 23)	43	27 (32, 22)	60	28 (33, 23)	-0.7
Practical work (hrs)	23	1.1 (1.3, 0.9)	43	1.1 (1.3, 0.9)	60	1.1 (1.3, 0.9)	0.004
Teacher demo (%)	23	16 (23, 9)	43	19 (25, 13)	60	15 (17, 13)	-1.0
Simulations (%)	23	7 (12, 2)	43	6 (8, 4)	60	6 (8, 4)	-0.2
Post – 16							
Practical work (%)	23	23 (30, 16)	49	25 (30, 20)	61	23 (27, 19)	-0.3
Practical work (hrs)	24	1.1 (1.4, 0.8)	49	1.1 (1.3, 0.9)	61	1.0 (1.2, 0.8)	-0.025
Teacher demo (%)	23	10 (15, 5)	49	10 (13, 7)	61	12 (14, 10)	0.9
Simulations (%)	23	7 (11, 3)	49	6 (9, 3)	61	8 (11, 5)	0.9

In year 3 of the study, staff were asked for their perception of how the proportion of lesson time they spent on practical work activities/experiments had altered since the last academic year (Figure 14 below and Table 13 in Appendix 3). In all age ranges and subjects, the majority of respondents indicated that the proportion had stayed the same. However, over 25% of respondents in the post - 16 age range in both state and independent schools in England reported an increase in the proportion of science lesson time spent on practical work.

These data should be considered in conjunction with the contemporaneously collected data which showed an increase in the proportion of lesson time spent on practical work in: science in state schools in England in the 11 – 14 age range (Table 9); chemistry and physics in independent schools in the 11 – 14 age range (Table 9); and in biology in state schools in the 14 – 16 age range (Table 10). There appears to be a discrepancy between the two sets of data in the post – 16 age range in independent schools, where reported time over the three years of the study showed a decrease in the proportion of lesson time spent on practical work in biology (Table 11).

Scottish state schools had the largest percentage of respondents reporting a decrease in the proportion of lesson time spent on practical work at 36% and 37% for the 14 – 16 and post -16 age ranges, respectively. However, the reported values indicated no change (Table 12).

Figure 14. All age ranges (England and Scotland): Stacked bar chart indicating the percentage of respondents who stated that the proportion of science lesson time spent on practical work activities/experiments had increased/decreased/stayed the same since the last academic year by subject (England only) – year 3 of the study. Respondents were heads of science and science teachers.



There were mixed opinions from participants of focus groups as to the reasons for choosing which types of activities to include in science lessons at both GCSE and A level. The varied views supported the findings of the quantitative survey, which showed a variation in the use of teacher demonstrations between different age ranges and subjects.

Example – Types of practical work

Mixed, non-selective, state school

Within a single school (in year 1 of the study) three members of staff had differing opinions on the reasons as to whether colleagues teaching physics would choose teacher demonstrations or hands on practical work.

Participant 1

> *Physics would tend to do more demos simply because of the equipment being bigger, bulkier, more expensive so you don't always have the opportunity to do it…if you've got 30 kids in the class… either in pairs or in threes …even keeping that amount of equipment would be awkward let alone buying it and keeping it up to date.*

Participant 2

> *[The physics teacher] is probably the least favourite in [doing practicals with students].*

Participant 3 (comparing activities in chemistry to those in physics)

> *I think you could have a demo and it might not work and then you are not always very likely to do it. If you've got 30 kids listening to you and it doesn't work whereas little test tube reactions are very straightforward and easier to do.*

The impact of the changes to the GCSE and A level curricula on experiments being undertaken were also discussed in focus groups and telephone interviews.

Example: Practical work activities

There were mixed comments as to whether the changes to the curriculum were leading to changes in the experiments being undertaken. However, staff were generally positive about the impact of the prescribed practical work.

Year 2 of the study

> *"It was so time consuming that I never bothered doing it with the A level students but because it [is now required] I thought … we are going to have to do it and the students suddenly could visualise what a wavelength could look like and visualise amplitude and displacement just by looking at it… I regret now not teaching it to them years ago. It was just the pack that made me say I have to do this and the students have to have this skill and they got the skill but the extra information they got from it was actually quite impressive."*
>
> *Mixed, non-selective, state school (Year 2 of the study)*

In year 3 of the study, staff in a different school commented that

> *"We do the same practicals - we would have done that with the rates of reactions - they have been going for years and we do the same practicals. However, now it is under a more…you feel you are delivering it more formally because you know that it is something they are going to be assessed on."*
>
> *Mixed, non-selective, state school (Year 3 of the study)*

8.1.2.2 Correlation between deprivation (IDACI and FSM) and amount of practical work

The correlation between the proportion of lesson time spent on practical work per week and the Income Deprivation Affecting Children Index (IDACI) based on the postcode of the school/college is shown in Table 13 for each of the three age ranges for schools in England. The greater the IDACI score, the higher the level of deprivation. The data show that in most cases (year 1 of the study in the post – 16 age range and all age ranges in years 2 and 3 of the study) the relationship between the proportion of lesson time spent on practical work per week and the level of deprivation is not significant. However, in year 1 of the study in the 11 – 14 and 14 – 16 age ranges, a small negative correlation is observed that is significant. This indicates that, for these two cases, the higher the level of deprivation of the school, the lower the proportion of lesson time each week spent on practical work.

Table 13. All subjects combined (England – state schools): Correlation between the proportion of science lesson time spent on practical work per week and school postcode IDACI score in each of the three survey years. Respondents were heads of science and science teachers. Statistically significant correlations are highlighted in bold with the level of significance stated below the table.

	Year 1		Year 2		Year 3	
	n	Correlation value (no units)	n	Correlation value (no units)	n	Correlation value (no units)
11 – 14 age range						
All subjects (state)	101	**-0.276***	157	0.001	313	-0.036
14 – 16 age range						
All subjects (state)	223	**-0.142***	276	-0.102	456	0.064
Post – 16 age range						
All subjects (state)	220	-0.052	240	-0.042	369	0.009

***P<0.05**

Table 14 shows the correlation between the proportion of science lesson time spent on practical work per week and the percentage of Free School Meal (FSM) uptake within a school. There was no significant correlation observed between the proportion of lesson time spent on practical work and FSM in any age range in all three years of the study.

Table 14. All subjects combined (England – state schools): Correlation between the proportion of science lesson time spent on practical work per week and Free School Meal uptake (FSM) in each of the three survey years. Respondents were heads of science and science teachers.

	Year 1		Year 2		Year 3	
	n	Correlation value (no units)	n	Correlation value (no units)	n	Correlation value (no units)
11 – 14 age range						
All subjects (state)	98	-0.089	152	-0.023	301	-0.068
14 – 16 age range						
All subjects (state)	210	-0.091	257	-0.114	426	0.006
Post – 16 age range						
All subjects (state)	175	-0.068	199	-0.130	311	-0.011

8.1.2.3 Frequency of students working as individuals, pairs and groups

Figure 15 to Figure 21 (and Table 14 in Appendix 3 to Table 20 in Appendix 3) show how often teachers reported that their students worked as individuals, in pairs or in groups when carrying out practical work activities or experiments.

In the 11 – 14 and 14 – 16 age ranges in all three year of the study, over 80% of respondents from state schools in England and over 90% of respondents from independent schools reported that their students worked in pairs half of the time or more when carrying out practical work activities in biology, chemistry and physics. In state schools in the post – 16 age range over 75% of respondents indicated that their students worked in pairs half of the time or more. In independent schools, over 50% of respondents teaching biology and chemistry indicated that their students worked in pairs half of the time or more. The value was higher in physics, where over 75% of respondents indicated that their students worked in pairs half the time or more.

Less than 30% of respondents across all subjects from state and independent schools in the 11 – 14 and 14 – 16 age ranges reported that their students had the opportunity to work as individuals half or most of the time. In the post – 16 age range more than 35% of respondents from state schools and more than 58% of respondents from independent schools reported that their students worked as individuals half of the time or more.

There was a split between state and independent schools in how often students worked in groups. In state schools in the 11 – 14 and 14 – 16 age ranges, over 54% of respondents indicated that their students worked in groups half or most of the time across all subjects and all three years of the study (other than in biological sciences in the 11 – 14 age range). In independent schools in the 11 – 14 and 14 – 16 age ranges, less than 40% of respondents reported their students working in groups half or most of the time (other than in science in the 11 – 14 age range). In the post – 16 age range 40% or less of respondents from state schools and 20% or less of respondents from independent schools indicated that their students worked in groups half of the time or more.

Due to the lower response rate in Scotland, it is not possible to provide a breakdown of the findings at the level of individual subjects. Averaging all subjects together shows that in all three years of the study across all age ranges, more than 78% of respondents indicated that their students worked in pairs half of the time or more when carrying out practical work activities. Fewer than 42% of respondents indicated that their students worked as individuals half the time or more. More than 33% of respondents indicated that their students worked in groups half the time or more across the three age ranges.

Figure 15. 11 - 14 age range (England – state schools): Stacked bar chart showing how often students worked as individuals, in pairs or in groups when carrying out practical work activities/experiments in each of the three survey years and by subject. Respondents were heads of science and science teachers.

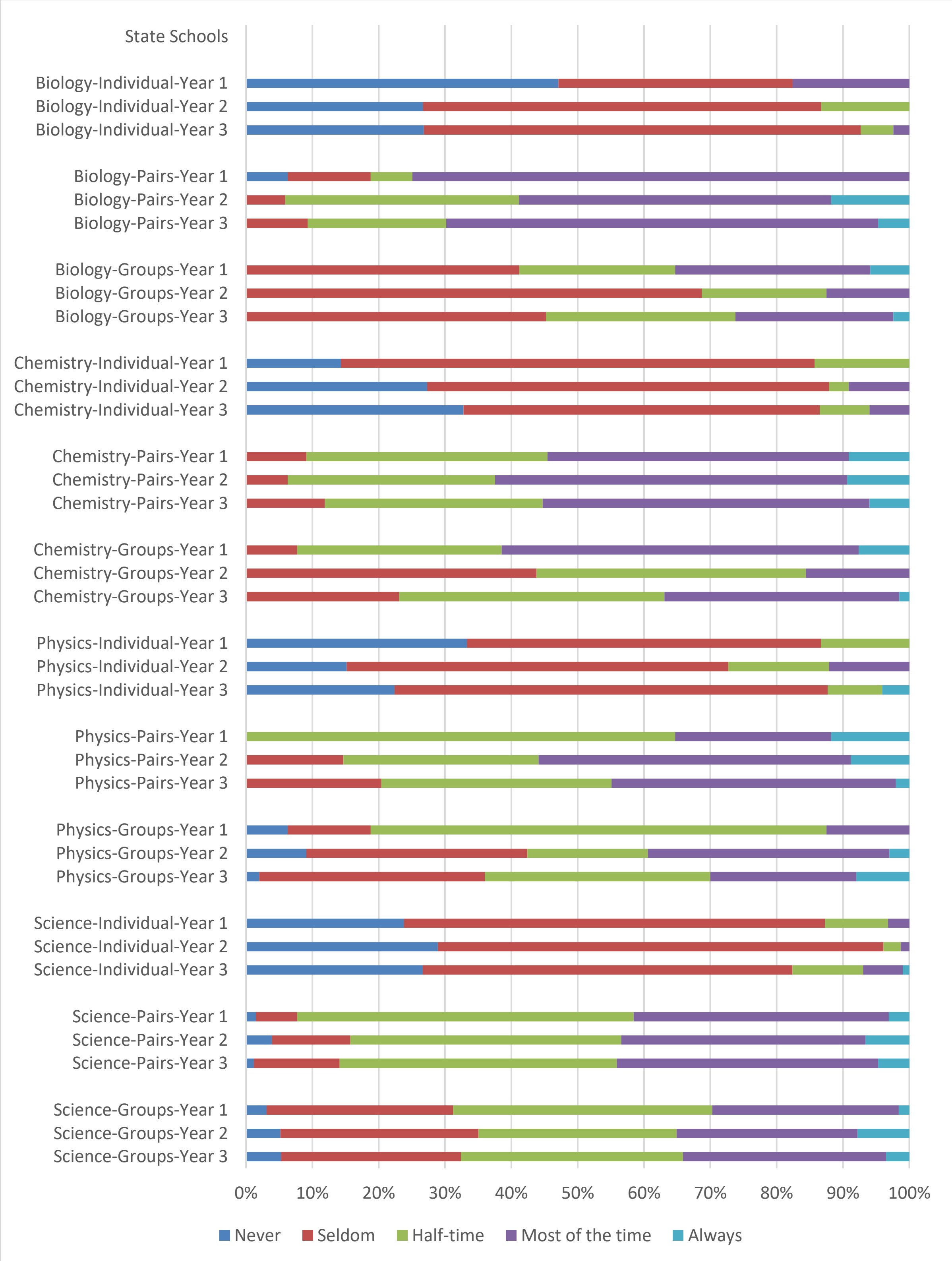


Figure 16. 11 - 14 age range (England – independent schools): Stacked bar chart showing how often students worked as individuals, in pairs or in groups when carrying out practical work activities/experiments in each of the three survey years and by subject. Respondents were heads of science and science teachers.

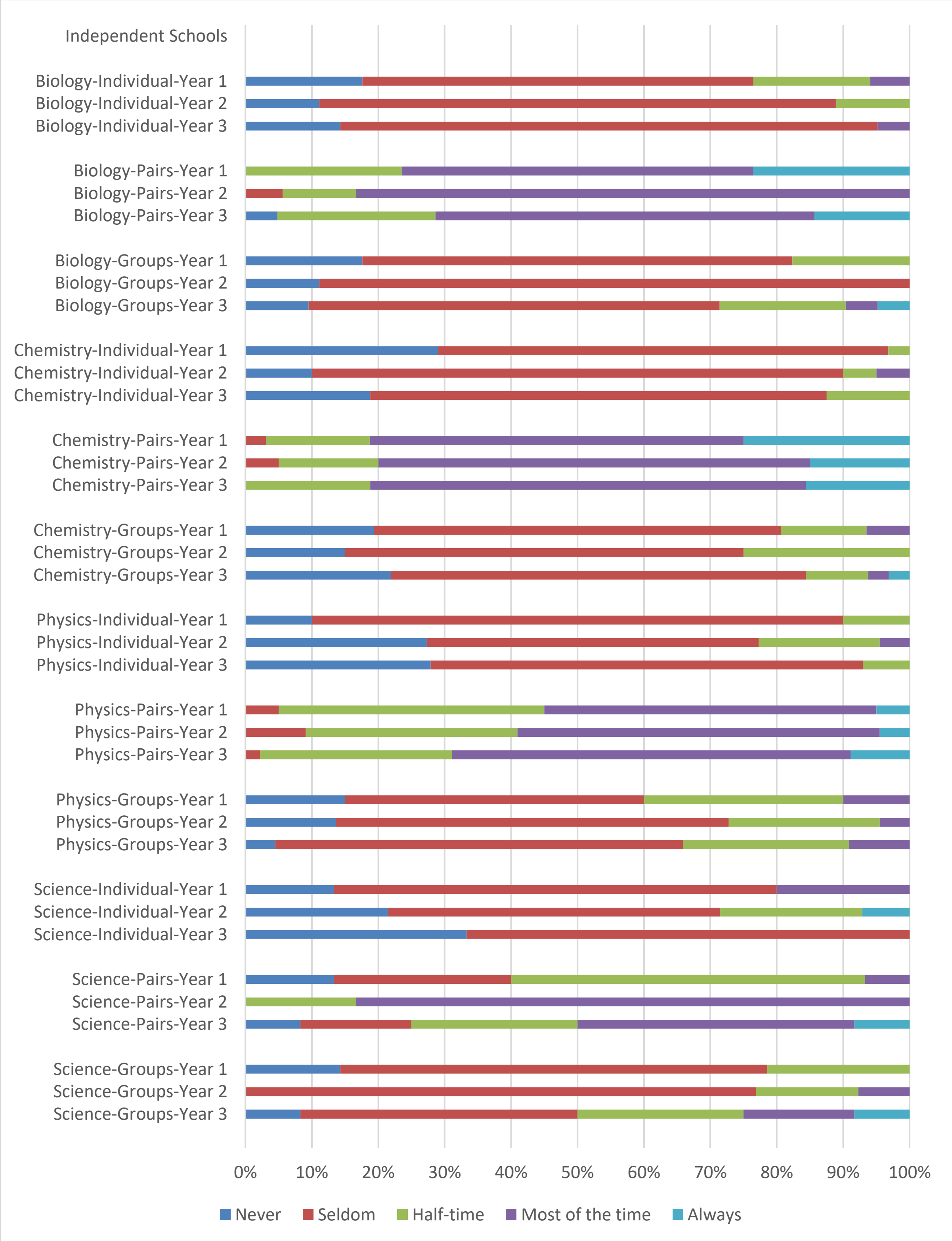


Figure 17. 14 - 16 age range (England – state schools): Stacked bar chart showing how often students worked as individuals, in pairs or in groups when carrying out practical work activities/experiments in each of the three survey years and by subject. Respondents were heads of science and science teachers.

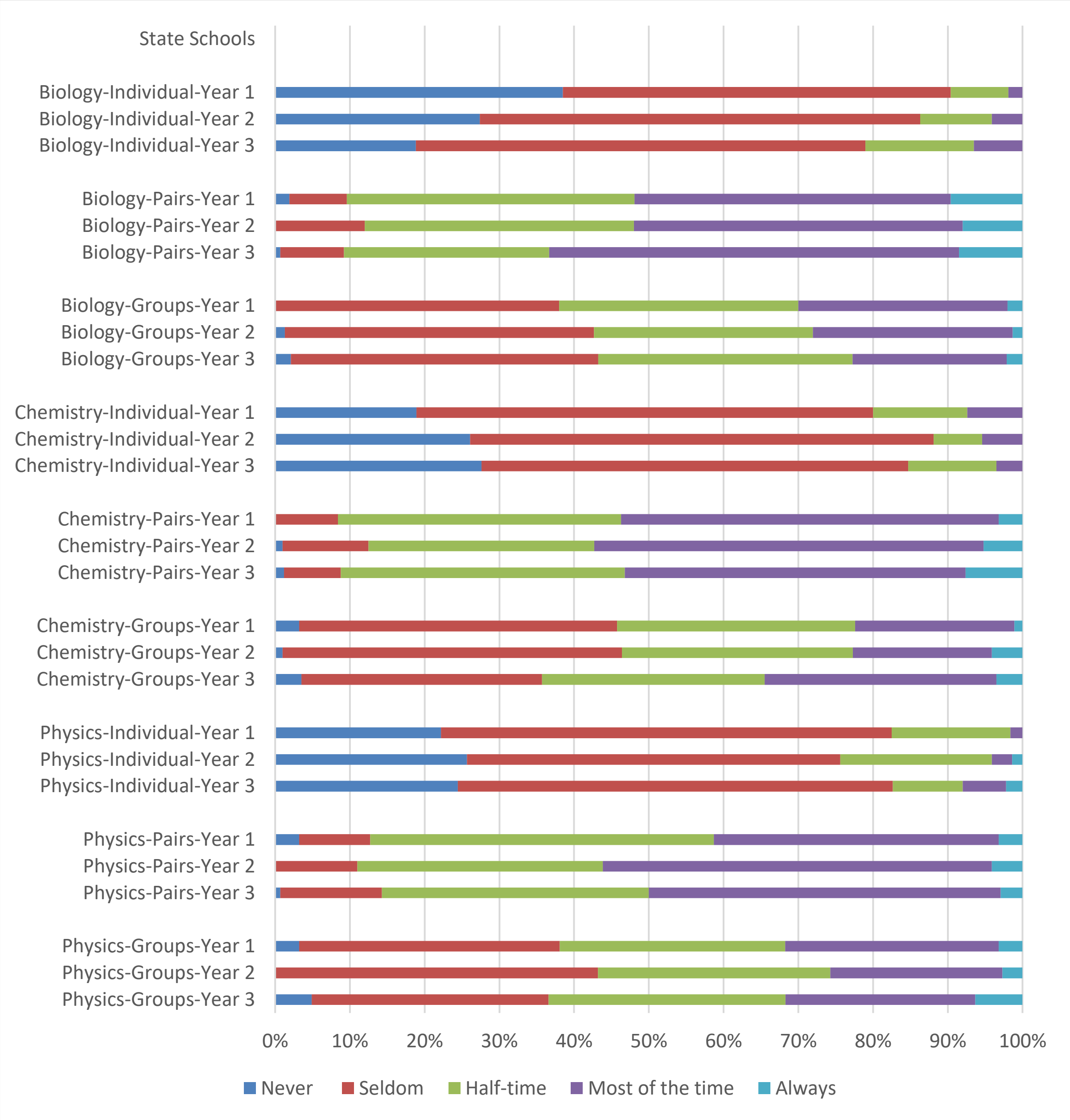


Figure 18. 14 - 16 age range (England – independent schools): Stacked bar chart showing how often students worked as individuals, in pairs or in groups when carrying out practical work activities/experiments in each of the three survey years and by subject. Respondents were heads of science and science teachers.

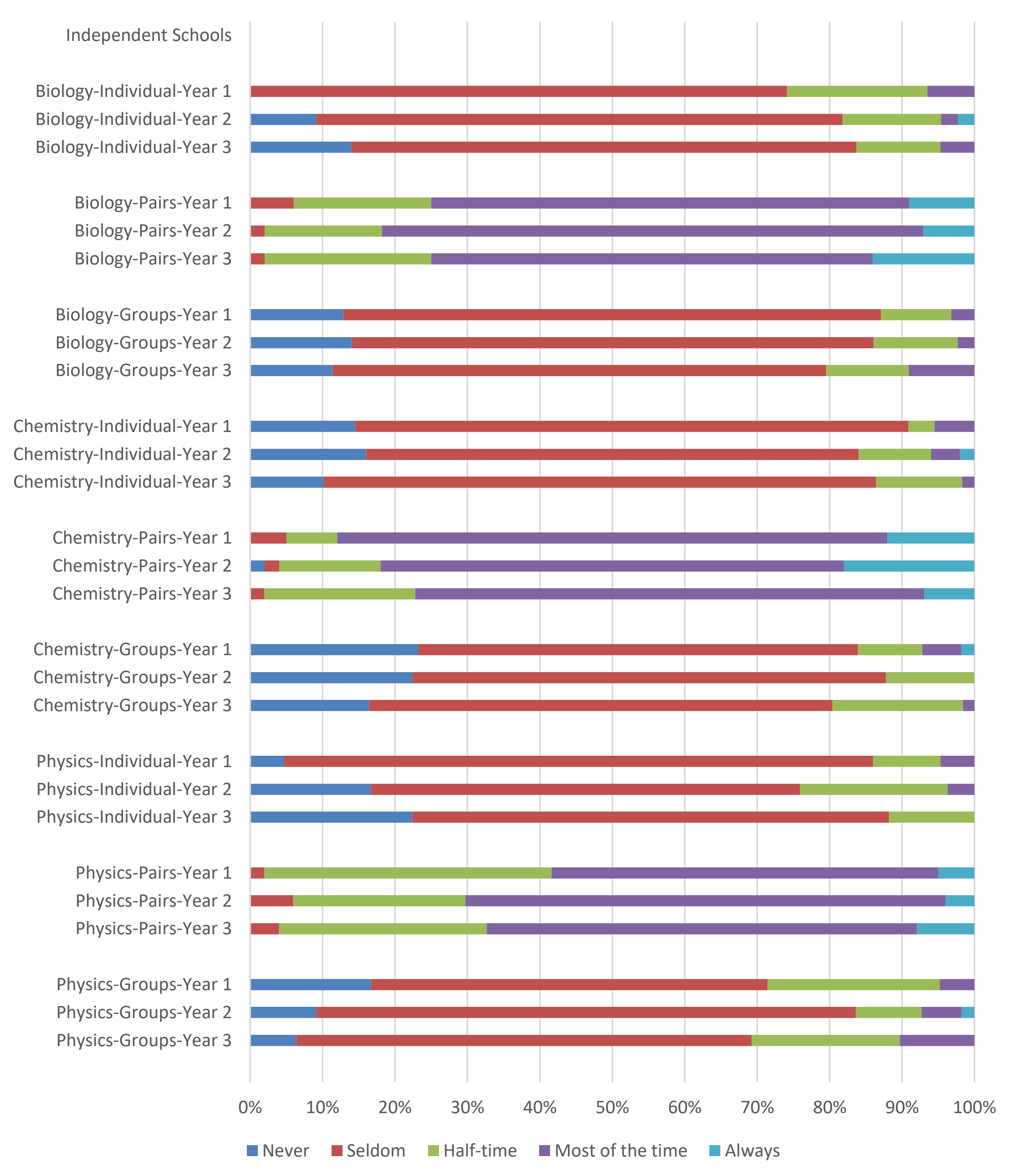


Figure 19. ***Post – 16 age range (England – state schools): Stacked bar chart showing how often students worked as individuals, in pairs or in groups when carrying out practical work activities/experiments in each of the three survey years and by subject. Respondents were heads of science and science teachers.***

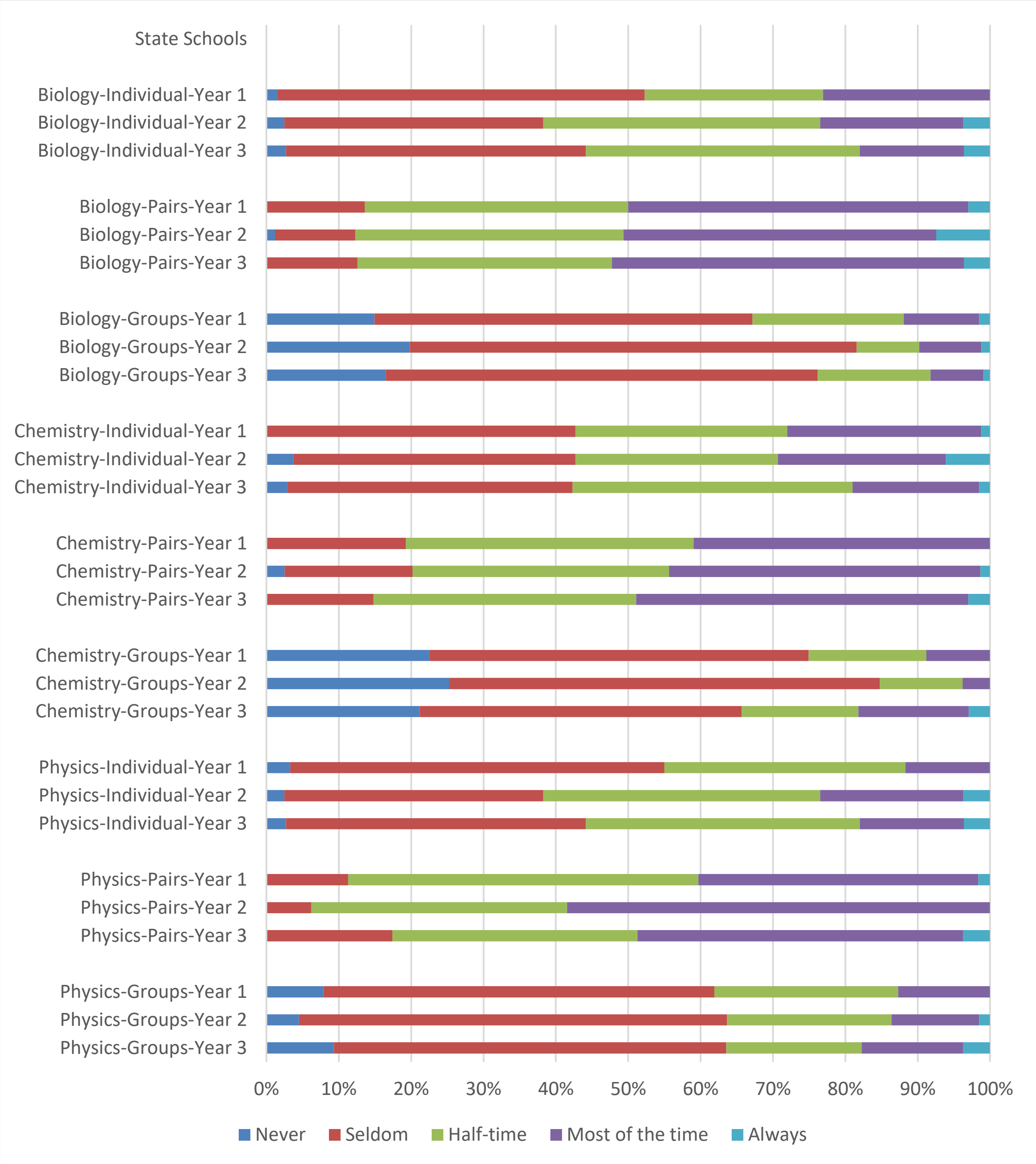


Figure 20. Post – 16 age range (England – independent schools): Stacked bar chart showing how often students worked as individuals, in pairs or in groups when carrying out practical work activities/experiments in each of the three survey years and by subject. Respondents were heads of science and science teachers.

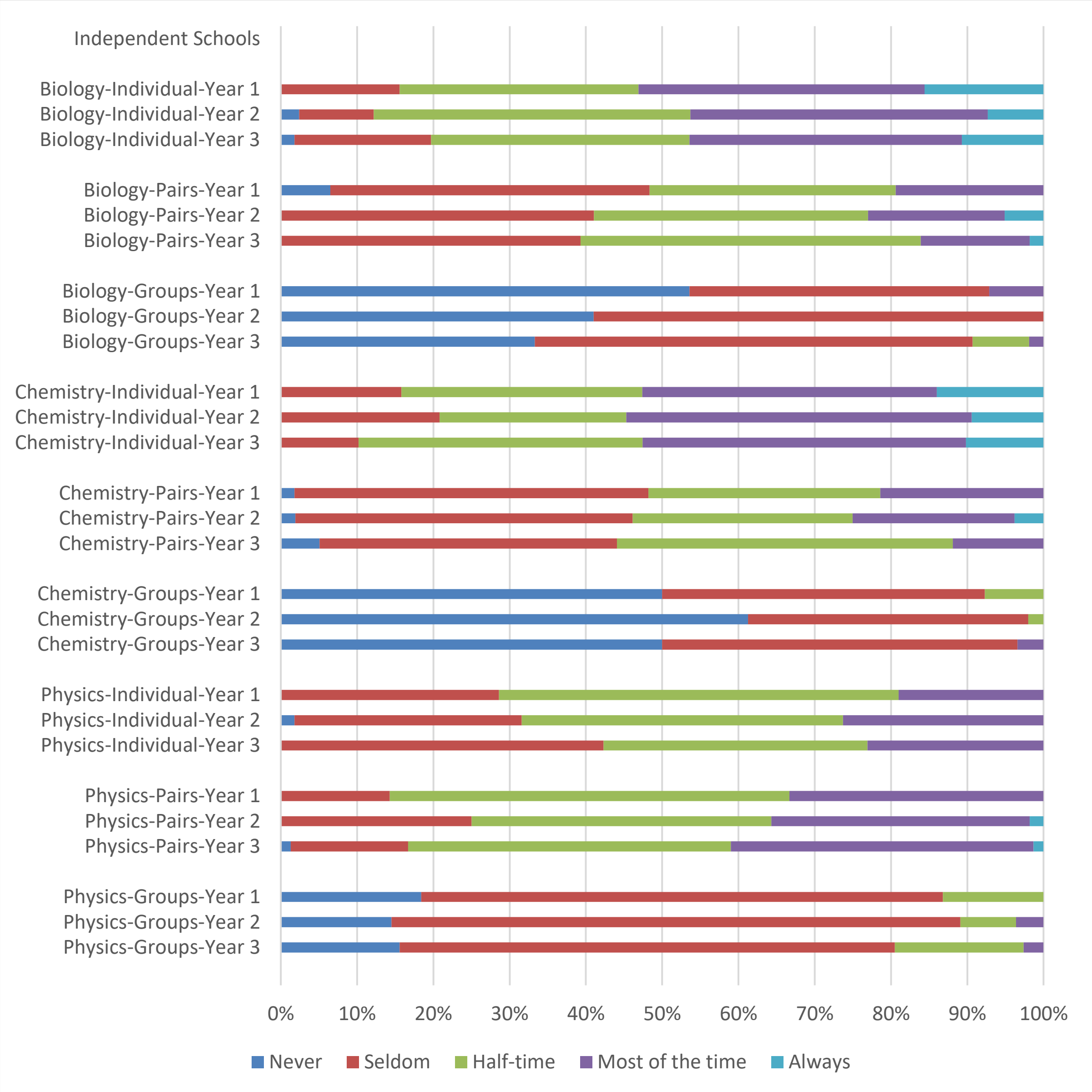
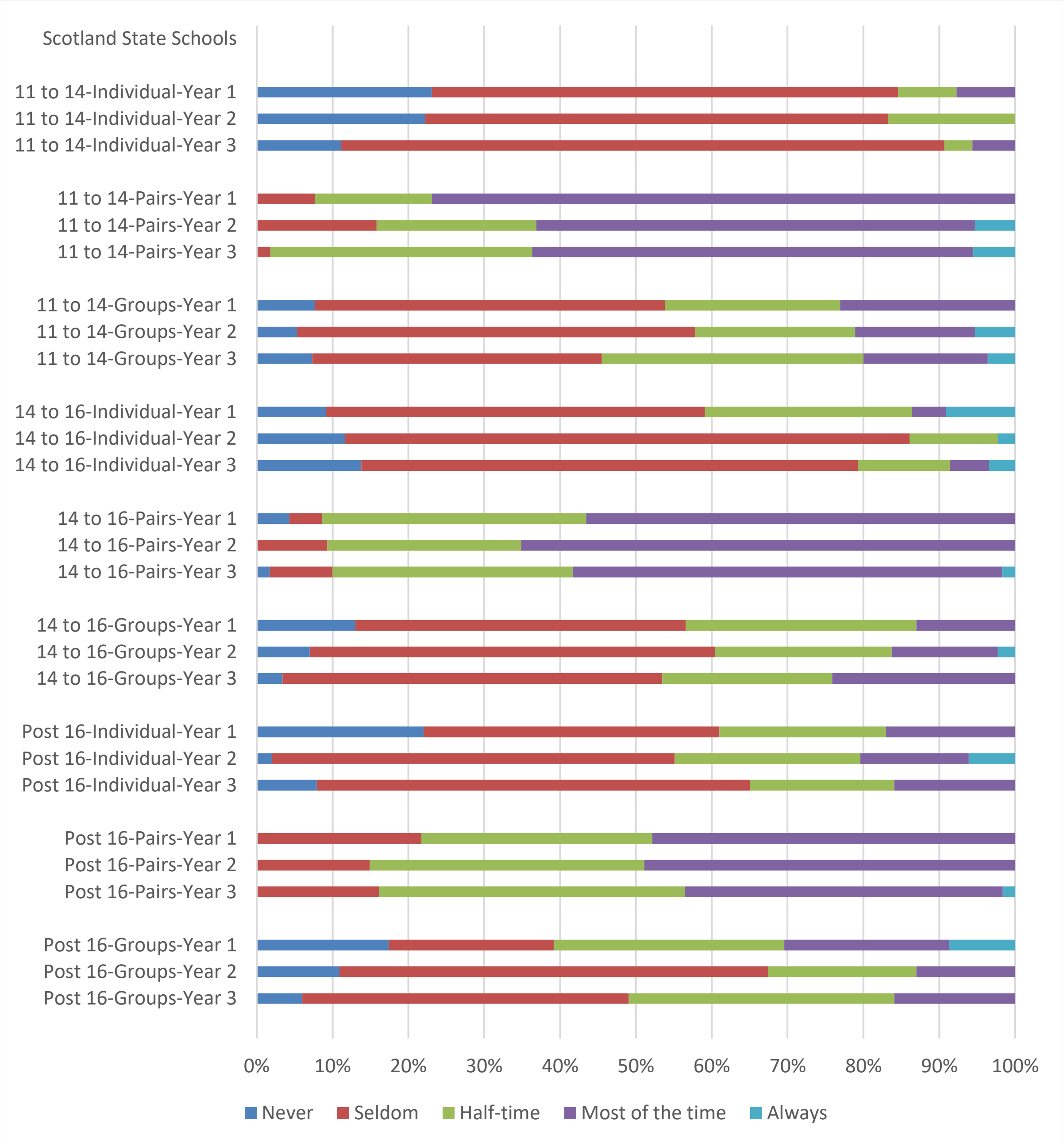


Figure 21. All age ranges (Scotland): Stacked bar chart showing how often students worked as individuals, in pairs or in groups when carrying out practical work activities/experiments in each of the three survey years. Respondents were heads of science and science teachers.



8.1.2.4 Tasks within practical work activities

Heads of science and science teachers were asked to indicate how frequently their students undertook a series of tasks within their practical work activities/experiments. The tasks listed on the survey have been combined into four categories:

- Evaluating experiments: 'write report about the activity/experiment', 'evaluate methods of activity/experiment', and 'evaluate other students' experiments'
- Analysing data: 'discuss purpose of experiment', 'evaluate uncertainty of data', and 'analyse conceptual ideas in the activity/experiment'
- Open-ended practical work: 'design own method' and 'propose a hypothesis'
- Following prepared instructions: 'following prepared instructions'

Staff were asked to indicate frequency using a five point scale with 5 indicating that students carried out the particular task in all activities, 4 – in most activities, 3 – in about half of the activities, 2 – in a few activities and 1 – in no activities. Figure 22 to Figure 28 (Table 21 in Appendix 3 to Table 24 in Appendix 3) show the findings. It is important to note that a single piece of practical work may contain multiple tasks, therefore, staff may report students undertaking several tasks at high frequencies.

In the 11 – 14 age range in both state and independent schools in all subjects and across all years of the study, staff reported that the most common task undertaken by students in their practical work activities and experiments was following prepared instructions. For all subjects in these age ranges, staff reported that students followed prepared instructions in more than half of practical work activities, in some cases this increased to 'most to all' activities. Analysing data was the next most common task undertaken by students, again taking place in at least half of activities. In the post – 16 age range the same pattern was observed in chemistry as in the 11 – 14 and 14 – 16 age ranges. However a different trend was observed for biology and physics in the post – 16 age range. In biology in state and independent schools and physics in independent schools, following prepared instructions and analysing data were carried out at the same frequency. In physics in state schools, analysing data was the task carried out most frequently by students in their practical work activities.

Across all age ranges and years of the study, students were reported to have evaluated experiments and carried out open-ended practical work in a few to half of the activities, with two exceptions. In chemistry in independent schools, students carried out open-ended practical work in only a few activities. In biology in the post – 16 age range, students evaluated experiments in about half of practical work activities. Comparing between age ranges, the only significant difference across age ranges was observed in post – 16 chemistry, where students carried out open-ended work less frequently than chemistry students in the 11 – 14 and 14 – 16 age ranges. However, a significant increase in the frequency with which open-ended practical work was carried out in post – 16 chemistry was also observed over the duration of the study, leading to no significant difference in frequency across the three age ranges in years 2 and 3 of the study.

Chemistry in state schools in the 11 – 14 age range showed several changes over the course of the study. An increase was observed in the frequency with which students followed prepared instructions as part of their practical work activities along with a decrease in how often students carried out open-ended practical work and evaluated experiments as part of their practical work activities. In the 14 – 16 age range in physics in state schools, an increase was observed in the frequency of students evaluating experiments as part of their practical work activities. A decrease in the frequency of students analysing data was observed in biology in independent schools. In the post – 16 age range in state schools, an increase in how often students evaluated experiments as part of their practical work activities was observed in biology, chemistry and physics over the three years of the study. An increase in how often chemistry students carried out open-ended practical work was also observed.

In Scotland in all years of the study in the 11 – 14 age range, the most common task students were reported to undertake in practical work activities was to follow prepared instructions. In the 14 – 16 and post – 16 age ranges following prepared instructions and analysing data were jointly the most common tasks undertaken in practical work activities.

Figure 22. 11 – 14 age range (England – state schools): Bar chart showing how often students carried out the stated tasks in their practical work in each of the three survey years and by subject. Scale: 1 – 5 with 1 indicating the task was undertaken in no activities and 5 indicating the task was included in all activities. Respondents were heads of science and science teachers. Respondents were heads of science and science teachers. 95% confidence intervals are displayed on the chart.

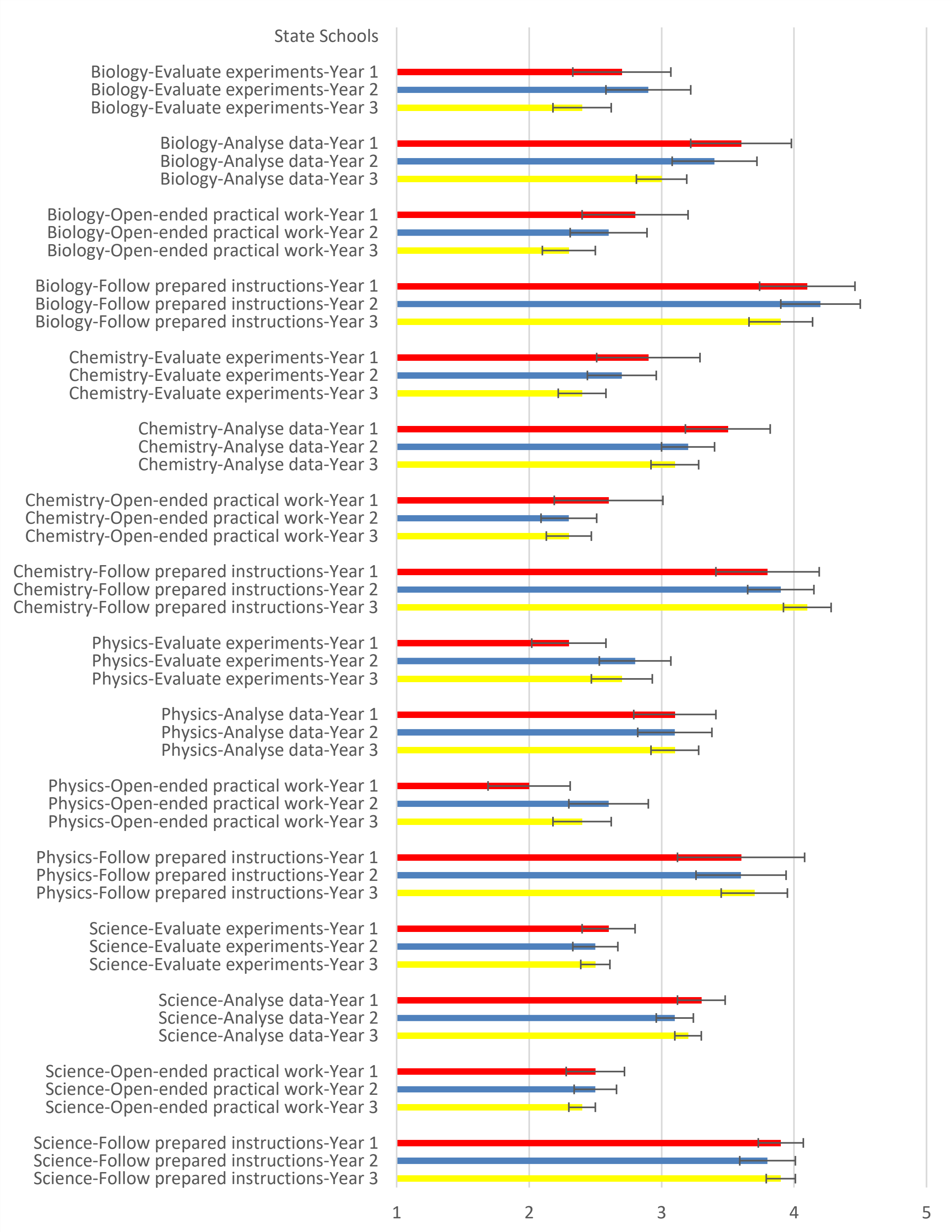


Figure 23. 11 – 14 age range (England – independent schools): Bar chart showing how often students carried out the stated tasks in their practical work in each of the three survey years and by subject. Scale: 1 – 5 with 1 indicating the task was undertaken in no activities and 5 indicating the task was included in all activities. Respondents were heads of science and science teachers. 95% confidence intervals are displayed on the chart.

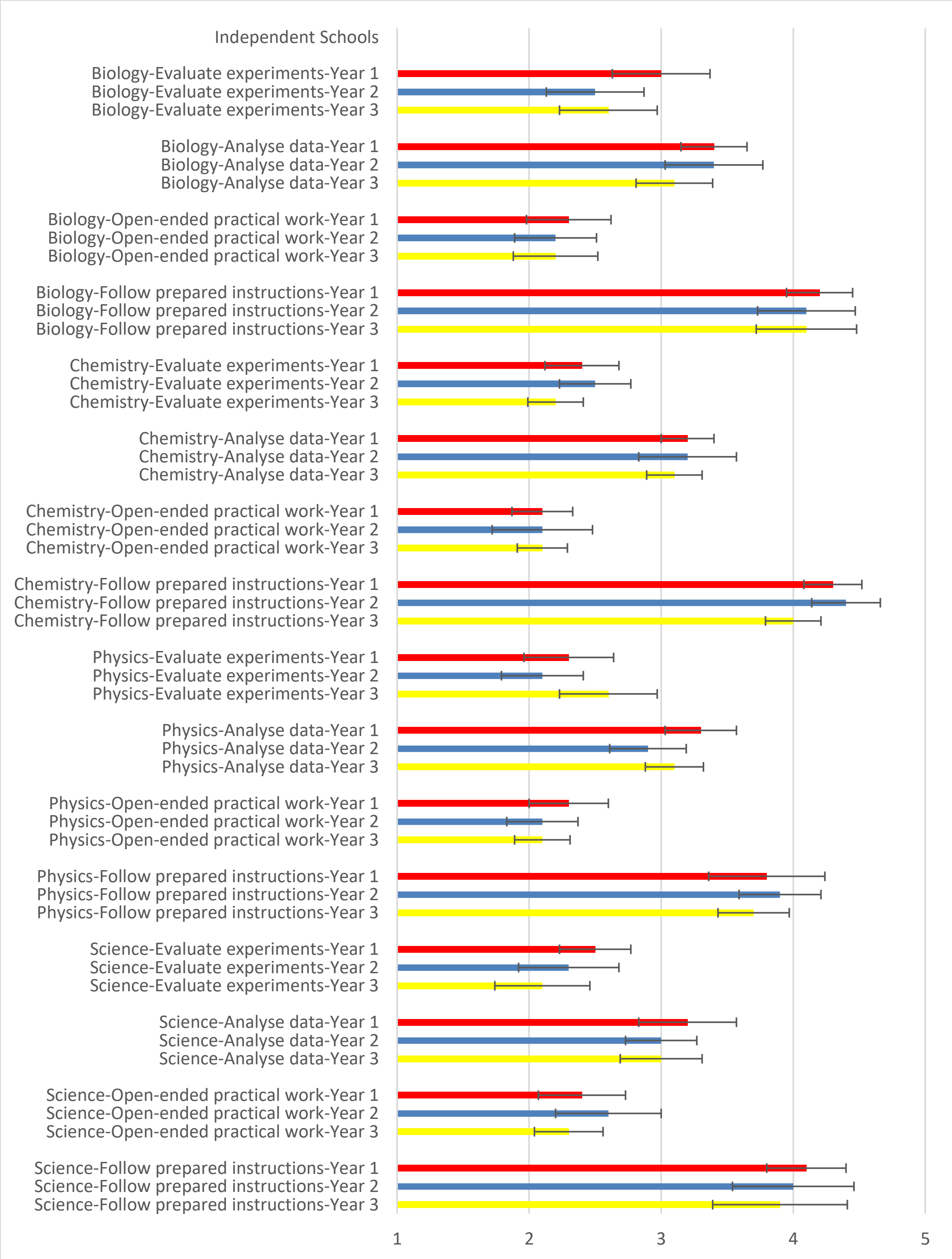


Figure 24. 14 – 16 age range (England – state schools): Bar chart showing how often students carried out the stated tasks in their practical work in each of the three survey years and by subject. Scale: 1 – 5 with 1 indicating the task was undertaken in no activities and 5 indicating the task was included in all activities. Respondents were heads of science and science teachers. 95% confidence intervals are displayed on the chart.

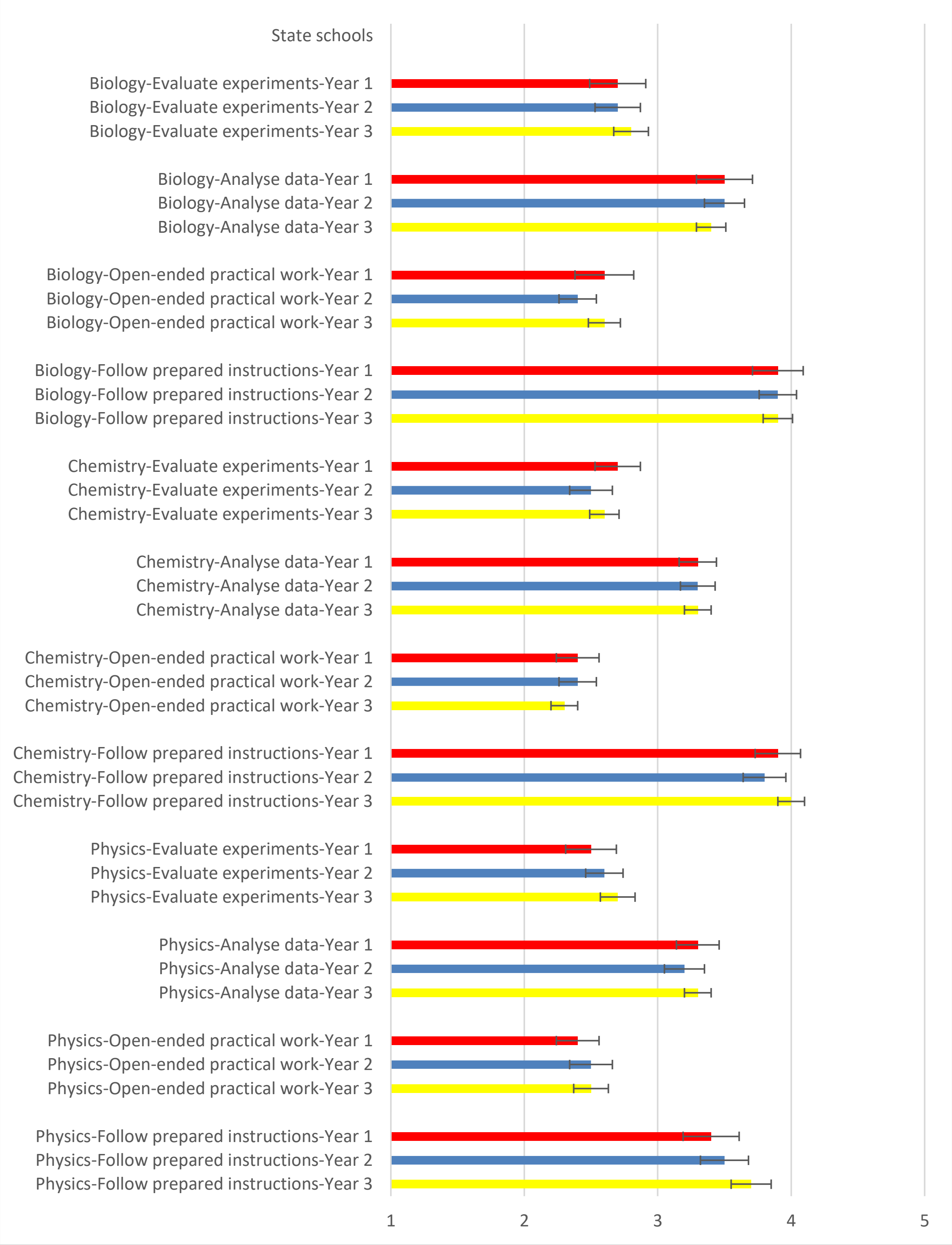


Figure 25. 14 – 16 age range (England – independent schools): Bar chart showing how often students carried out the stated tasks in their practical work in each of the three survey years and by subject. Scale: 1 – 5 with 1 indicating the task was undertaken in no activities and 5 indicating the task was included in all activities. Respondents were heads of science and science teachers. 95% confidence intervals are displayed on the chart.

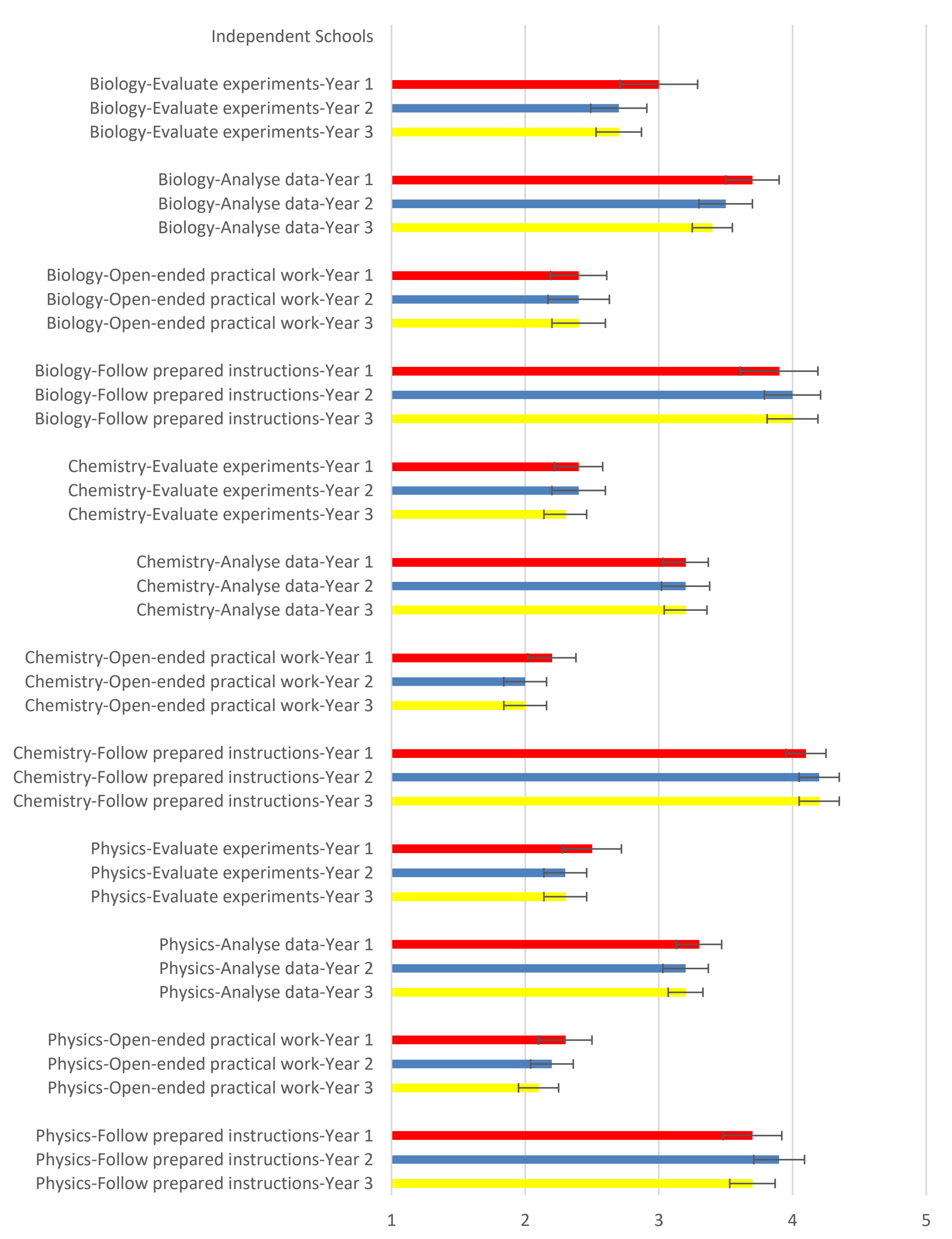


Figure 26. Post – 16 age range (England – state schools): Bar chart showing how often students carried out the stated tasks in their practical work in each of the three survey years and by subject. Scale: 1 – 5 with 1 indicating the task was undertaken in no activities and 5 indicating the task was included in all activities. Respondents were heads of science and science teachers. 95% confidence intervals are displayed on the chart.

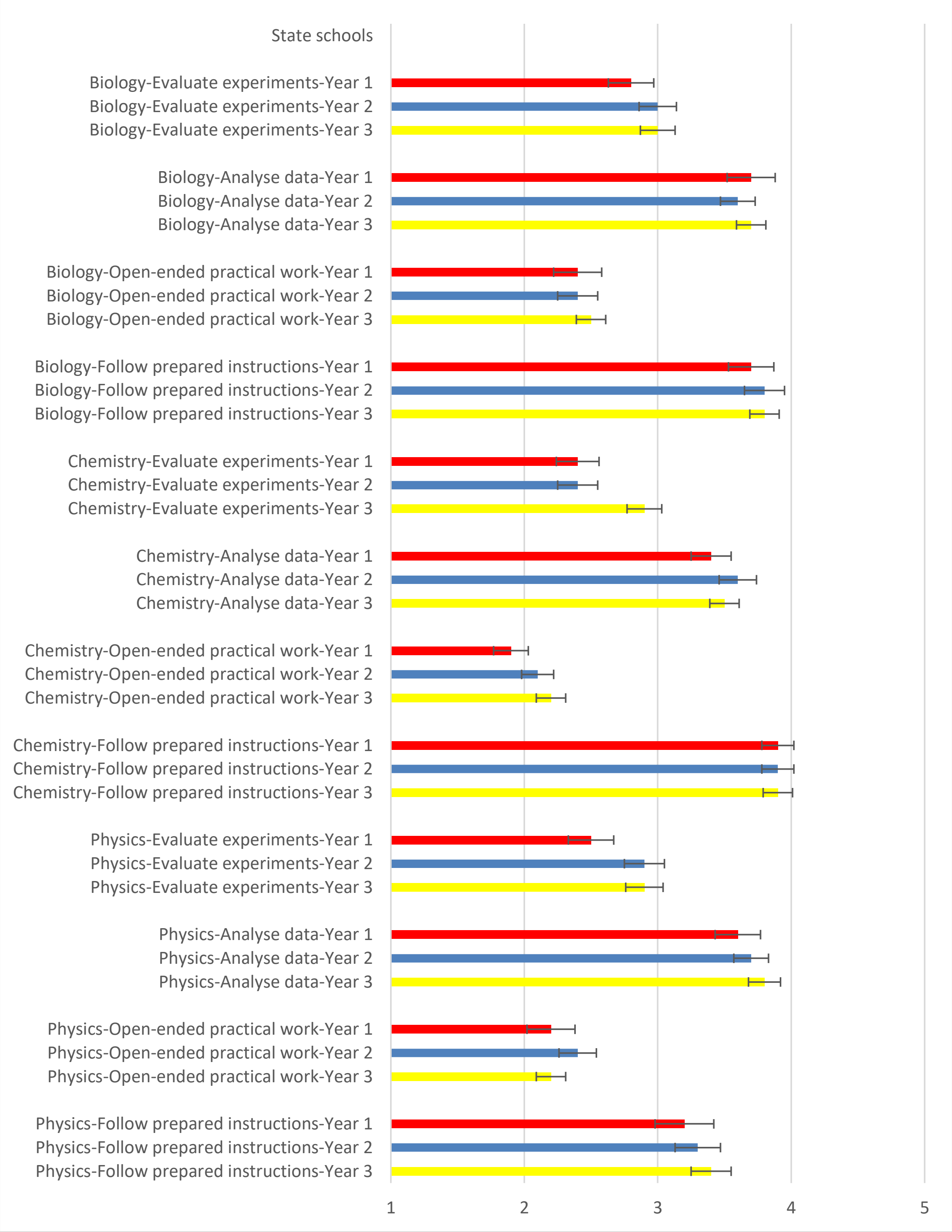


Figure 27. Post – 16 age range (England – independent schools): Bar chart showing how often students carried out the stated tasks in their practical work in each of the three survey years and by subject. Scale: 1 – 5 with 1 indicating the task was undertaken in no activities and 5 indicating the task was included in all activities. Respondents were heads of science and science teachers. 95% confidence intervals are displayed on the chart.

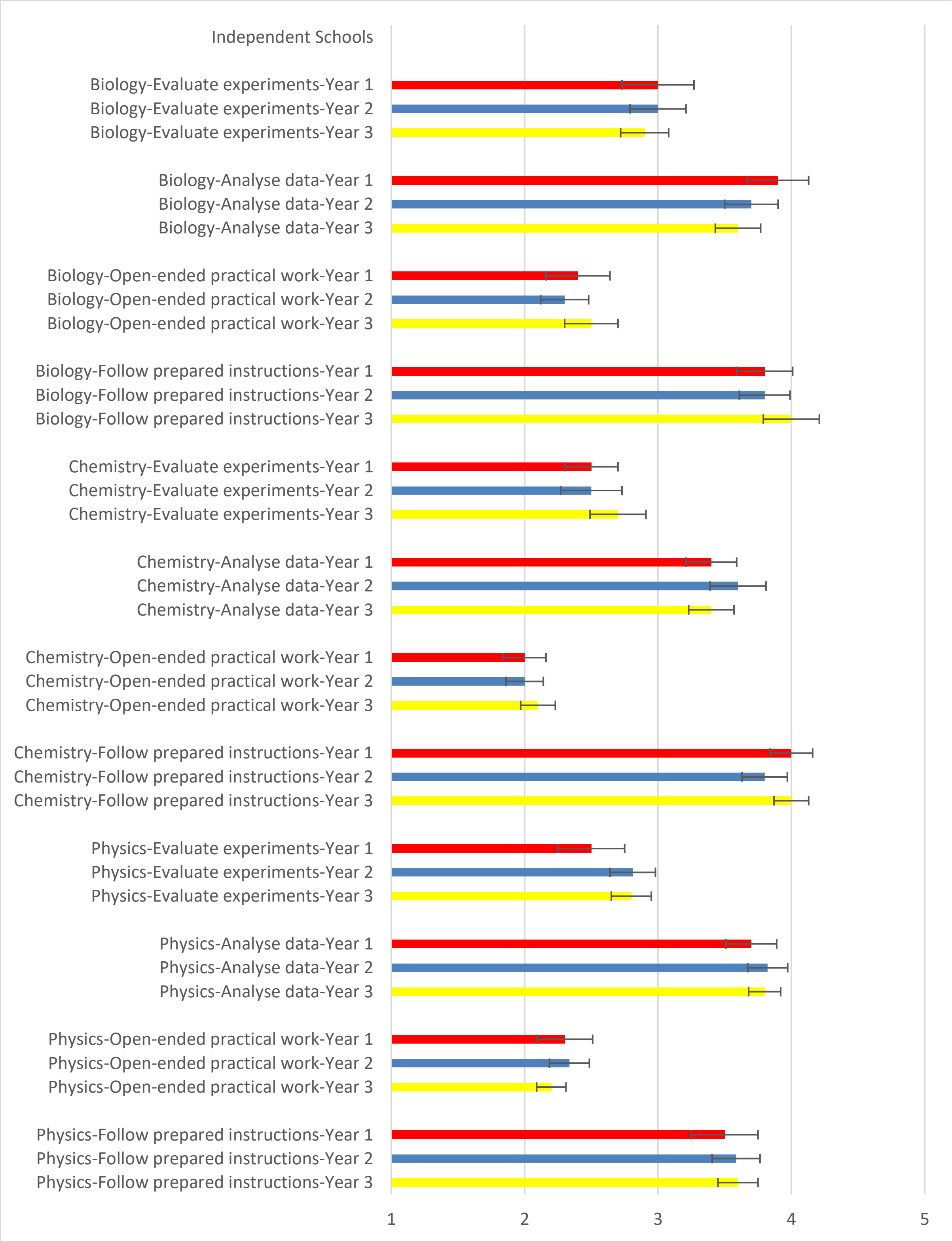
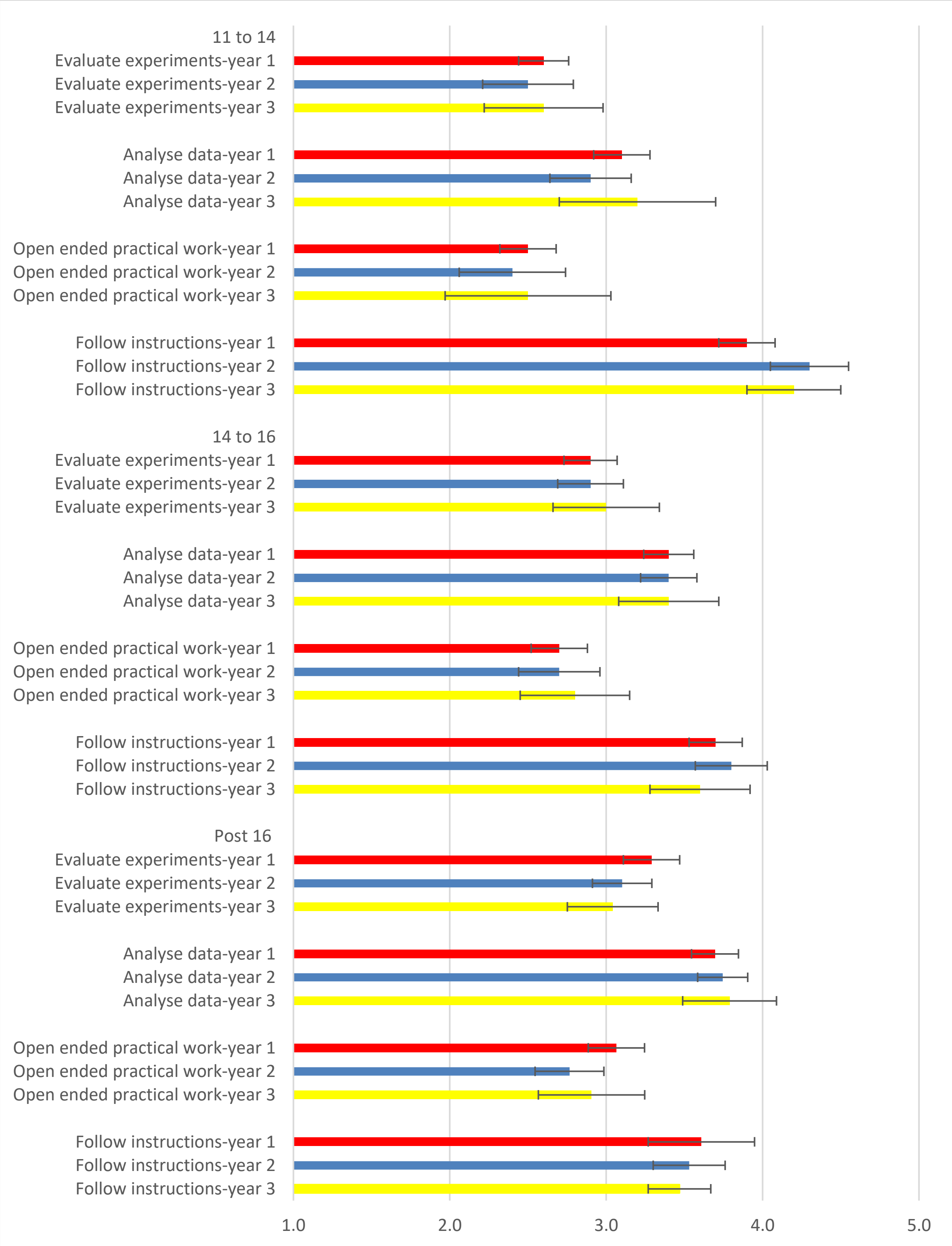


Figure 28. All age ranges (Scotland): Bar chart showing how often students carried out the stated tasks in their practical work in each of the three survey years. Scale: 1 – 5 with 1 indicating the task was undertaken in no activities and 5 indicating the task was included in all activities. Respondents were heads of science and science teachers. 95% confidence intervals are displayed on the chart.

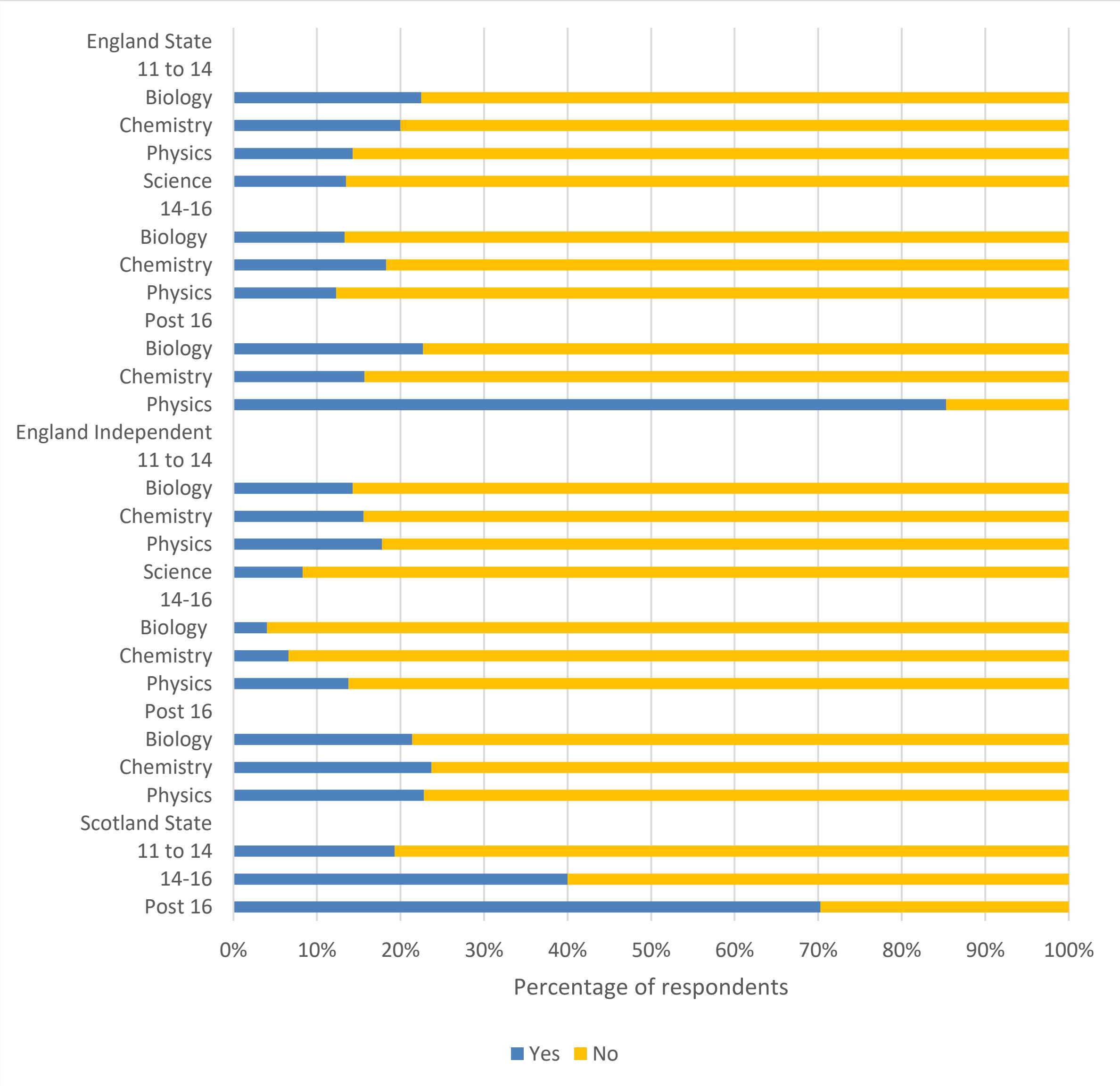


Open-ended, extended investigation

In year 3 of the study, heads of science and science teachers were asked whether their students had an opportunity to carry out open-ended, extended investigation (longer than 2 weeks) involving practical work in lesson time in the last academic year.

Less than a quarter of respondents in each age range and subject indicated that their students had had an opportunity to carry out this type of task (Figure 29 below and Table 25 in Appendix 3), other than two notable exceptions: physics in the post – 16 age range in state schools in England (85% of respondents reported that students did have the opportunity to carry out this open-ended, extended investigations); and post – 16 students in Scotland where 70% of staff reported their students did have this opportunity.

Figure 29. All age ranges (England and Scotland): Stacked bar chart showing whether staff reported that their students had an opportunity to carry out open-ended, extended investigation (longer than 2 weeks) involving practical work in the last academic year by subject. The question relates to year 3 of the study. Respondents were heads of science and science teachers.



Discussion within the focus groups in England highlighted ways in which schools were adapting to the changes in the curriculum. Several schools commented how they considered stopping the individual extended investigation project in the Salters[7] A level to be detrimental to students' development and understanding of conducting practical experiments. Note that a single day dedicated to practical work as described in the example below would not have met the definition of an "open-ended extended investigation".

Example: Type of practical work – open-ended and extended practical work

Staff commented on how they were changing their working practices in relation to the curriculum changes at both GCSE and A level.

> *"I don't think we have much of an opportunity to do something truly open ended with the sixth form. We can design it you know and I guess we will try as much as we can. I used to teach the Salters A level where they truly could choose any topic and they used to go in any direction and we used to get some fantastic work"*
>
> *Boys, selective, independent school (Year 2 of the study)*
>
> *"One of the things we are setting up, coming up now, because the course work element has been taken away is [that] the year 10s are having an experience day, essentially, where they are going to be off timetable for the day and running through a science experiment. So they will be planning, doing, analysing, reviewing and evaluating over the course of a full day and we are running that in June."*
>
> *Mixed, non-selective, state school (Year 3 of the study)*

[7] https://www.ocr.org.uk/qualifications/as-and-a-level/chemistry-b-salters-h033-h433-from-2015/

Outdoor practical work

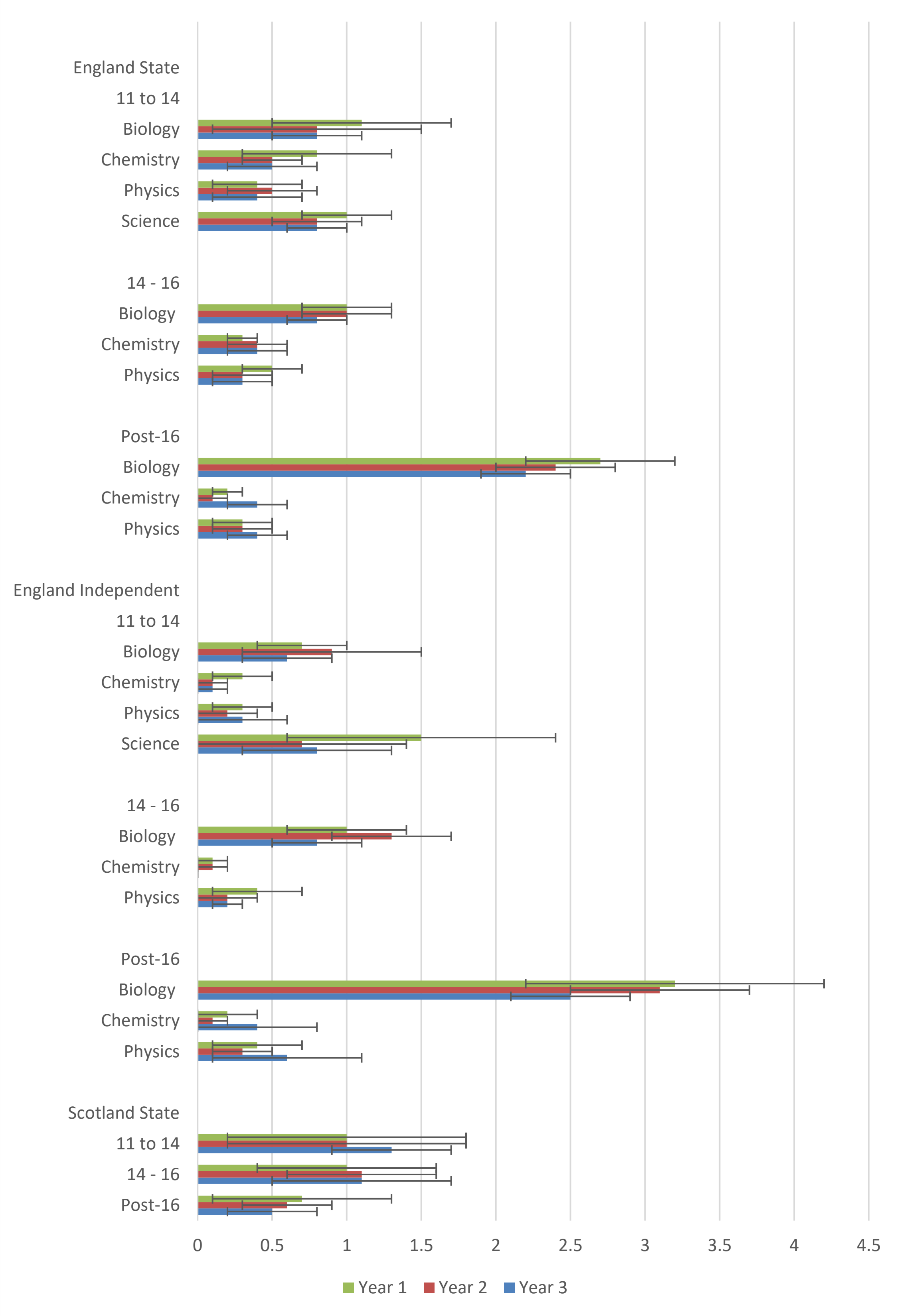
Across all age ranges and subjects in all three years of the study, respondents teaching in state schools reported that on average students spent between 0.1 and 1.1 days (state schools) and 0 and 1.5 days (independent schools) per year on outdoor practical work (Figure 30 below and Table 26 in Appendix 3). The exception to this was in the post – 16 age range for biology students, who spent over 2 days per year on outdoor practical work. In the 14 – 16 and post – 16 age ranges in both state and independent schools, biology students spent more time on outdoor practical work than chemistry students (other than in the 14 – 16 age range in year 3 of the study) and physics students (other than in year 1 of the study in the 14 – 16 age range). Responses from qualitative interviews and focus groups identified the additional time for biology students as being spent on residential fieldwork.

State school pupils spent more time per year on outdoor practical work than students at independent schools in chemistry in the 11 – 14 age range in year 2 of the study and in the 14 – 16 age range in year 3, however, in both cases, this was less than half a day per year in total.

In Scotland, students spent between 0.5 and 1.3 days per year on outdoor practical work.

Based on the amount of lesson time spent on practical work and the number of practical work activities carried out by biology students in the 14 – 16 and post – 16 age ranges, a first impression may be gained that biology students' practical work exposure is less than chemistry and physics students. However, when combined with the findings relating to outdoor practical work, where biology students have significantly more time than chemistry and physics students, it suggests that biology students are not being disadvantaged, but instead, practical work is concentrated into outdoor fieldwork activities for students studying biology.

Figure 30. All age ranges (England and Scotland): Bar chart showing the number of days per year allocated to outdoor practical work in each of the three survey years and by subject (in England). Respondents were heads of science and science teachers. 95% confidence intervals are displayed on the graph.



8.2 What are the main insights into any influences on the quantity and breadth of science practical work undertaken in schools?

This section considers the factors that affect the amount and type of practical work staff choose to carry out with their students including; the qualifications and experience of science teachers, the ability and behaviour of students, and student motivation.

Key findings:

Heads of science, science teachers and technicians in the focus groups and telephone interviews reported that shortages of appropriately qualified staff made teaching practical science more difficult.

Participants in the focus groups and telephone interviews stated that the behaviour and ability of students played a role for staff when deciding the type or length of activity to include as practical work. Consistent views were also expressed that the practical element of science lessons was a great motivation for students and was often a key part of their decision to study the subject at a higher level.

There was an increase in the number of hours reported to be spent preparing for and carrying out statutory practical assessment per academic year over the course of the study for biology in state schools in all age ranges. Chemistry in independent schools in the post – 16 range also showed a significant increase in the number of hours spent preparing for practical work over the course of the study.

Of the staff responding to the survey who were teaching a year 9 cohort in England, 88% of state school and 81% of independent school respondents indicated that they had commenced teaching the GCSE curriculum in year 9, to extend teaching time for the GCSE course to three years.

8.2.1.1 Qualifications of science teachers

In years 2 and 3 of the study, respondents were asked to report on their highest qualification in their specialist science subject. Figure 31 to Figure 33 (and Table 27 in Appendix 3 to Table 29 in Appendix 3) show the highest qualification of respondents by the subject they were teaching. A small number of respondents indicated their highest qualification was not one of: Doctorate degree, Masters degree, Bachelor degree or Post – 16 qualification. Additional information is available in Section 3.4 in Appendix 2. Analysis of respondents' qualifications shows our sample is more highly qualified than the overall teaching workforce (Gov.uk, 2018). Results should be read with this in mind.

The data were investigated to identify whether there was a correlation between the qualifications of respondents and the proportion of lesson time they reported for carrying out practical work, teacher demonstrations and computer simulations per week (Table 30 in Appendix 3 to Table 32 in Appendix 3). Although some qualification/subject/activity combinations did occasionally produce individual significant correlation values, there was no overall systematic association between teacher qualifications and the types of activities carried out in science lessons.

Heads of science, science teachers and technicians in the focus groups and telephone interviews reported that shortages of appropriately qualified staff made teaching practical science more difficult.

Example: Factors affecting practical work – Availability of qualified teachers

Availability of qualified staff was raised as an issue which significantly affects practical work by several schools participating in focus groups and interviews. Two schools gave details of the challenges that they were facing in year 2 of the study.

> *"There has been an issue for me with non-specialist teachers …where they are doing less and I have been trying to encourage them. Last year we had a PE teacher teaching year 7 and trying to give her the confidence to do some practical was the issue there and I know that is an issue in other schools."*
>
> *Girls, selective, independent school (Year 2 of the study)*
>
> *"The biggest problem over the last few years has been staffing, there just haven't been enough qualified staff … there are no suitable science staff to cover any shortage you have and we have been short on staff … 95% of the time over the last 5 years and that means that classes are going uncovered and parents hear about it and move them to other schools where they think they will have a better science provision…It is not specific [to our school] it is a problem across [our region]."*
>
> *Mixed, non-selective, state school (Year 2 of the study)*

Figure 31. All age ranges (England – state schools): Stacked bar chart showing the qualifications of respondents in years 2 and 3 of the study in their specialist science subject by the subject they reported on teaching for the survey. Respondents were heads of science and science teachers.

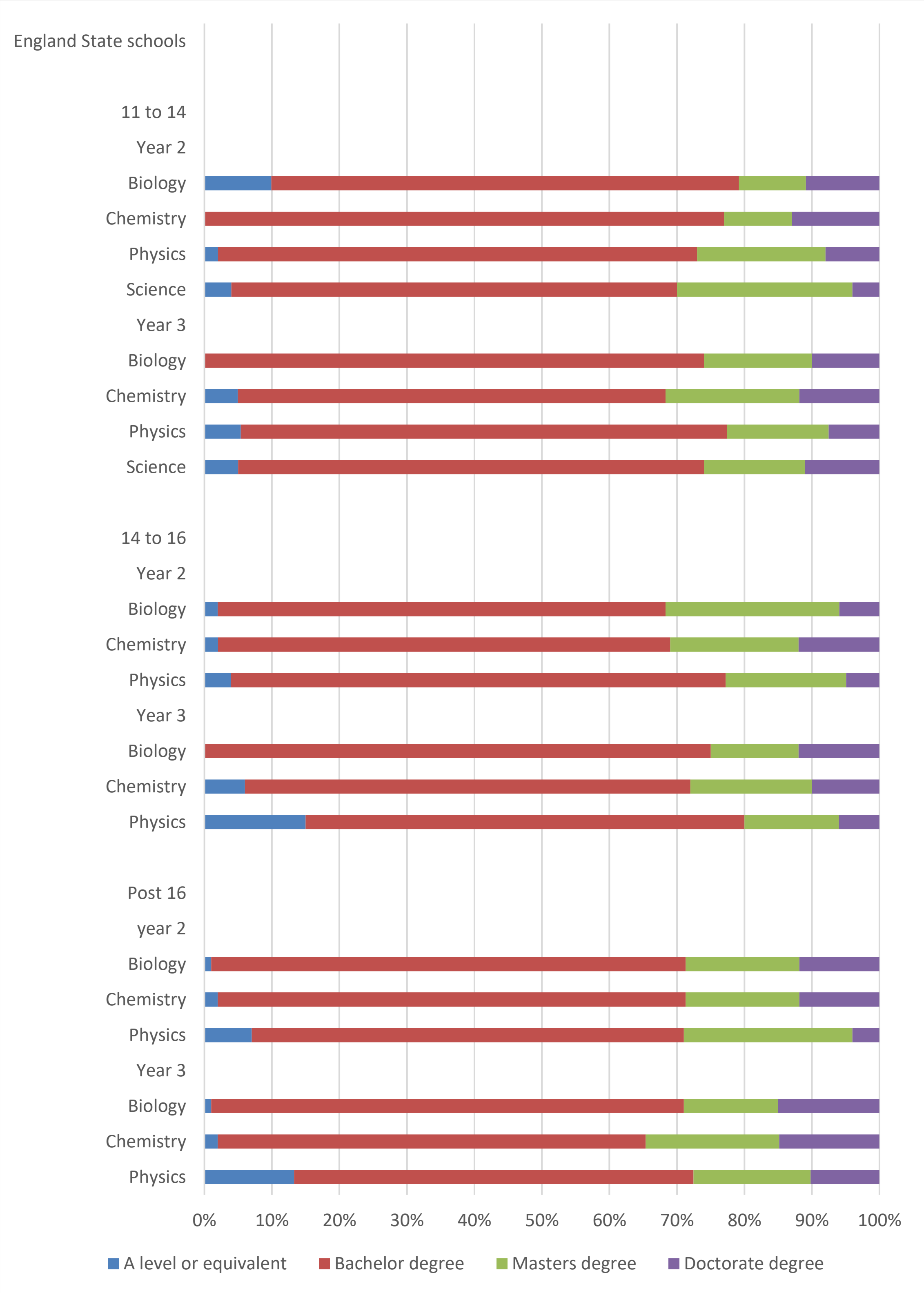


Figure 32. All age ranges (England – independent schools): Stacked bar chart showing the qualifications of respondents in years 2 and 3 of the study in their specialist science subject by the subject they reported on teaching for the survey. Respondents were heads of science and science teachers.

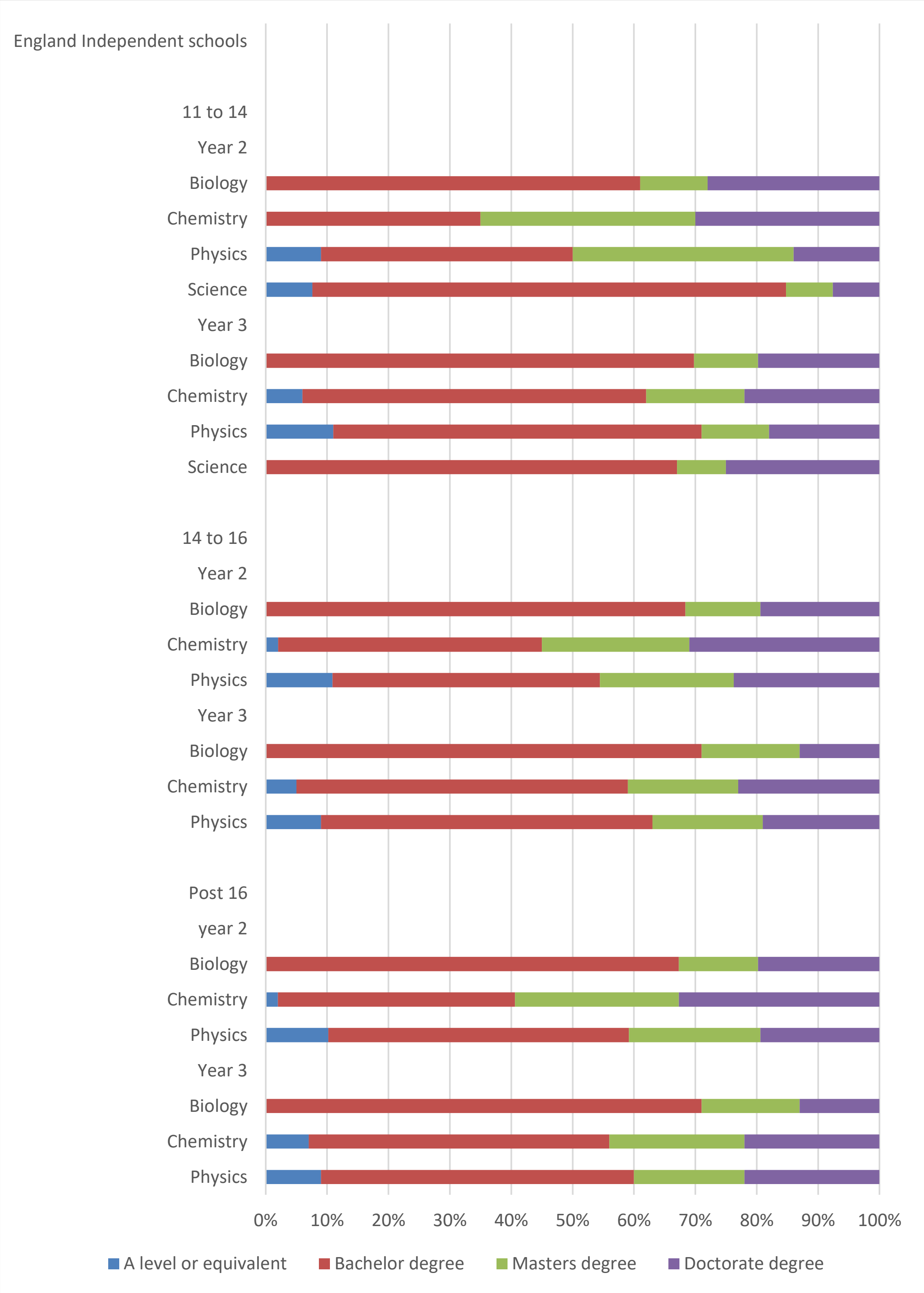
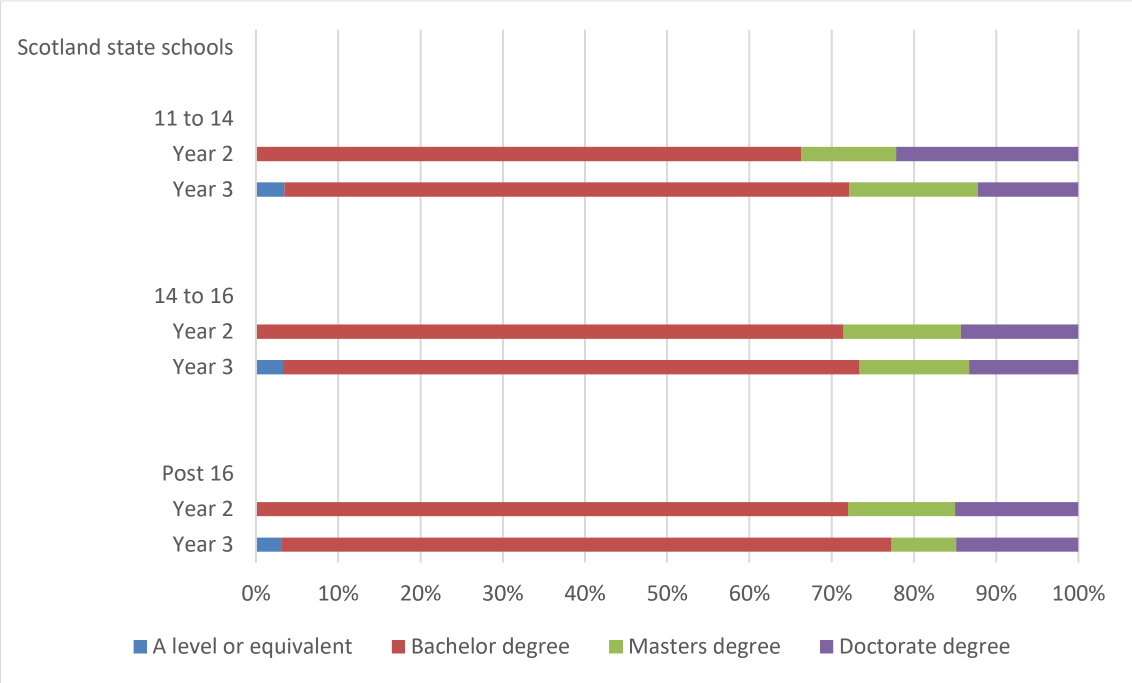


Figure 33. All age ranges (Scotland): Stacked bar chart showing the qualifications of respondents in years 2 and 3 of the study in their specialist science subject. Respondents were heads of science and science teachers.



8.2.1.2 *Student ability, behaviour and motivation*

The behaviour and ability of students was a consideration for staff when deciding the type or length of practical activity to include in science lessons.

Example: Factors impacting on choice of practical work – Student ability and behaviour

Mixed, non-selective, state school

Staff commented on how the ability and behaviour of students impacted on the type of activity and style of practical work that they chose to undertake.

Year 1 of the study

> *"If you've got a lower set and the behaviour is bad then yes that is going to influence how [practicals are taught]. You might hold that as a carrot over them that if they behave then they can do it. If you know you are going to have a poorly behaved class and you've got scalpels and glassware and then yeah you are going to be less likely to do it which is a shame but that's life."*

Year 3 of the study

> *"You might think you want [the lower ability sets] out of their seats and they are frustrated and they don't like writing and so the whole double lesson is too long to sit there and so you might want short practicals where you can do a quick little demonstration or they can do a quick little practical and get a result. Whereas, with the more academic classes who are happier writing you might do a practical once a week and do a longer practical."*

Participants in the focus groups and telephone interviews were consistent in their view that the practical element of science lessons was a great motivation for students and was often a key part of their decision to study the subject at a higher level.

Example: Factors impacting on practical work – Student motivation

Heads of science, science teachers and technicians participating in focus groups consistently reported practical work as being highly motivating for students to continue to study science.

> *"I have had feedback from parents, when we meet the parents, when they come in on the equivalent of parents' evenings and they say that their son or daughter enjoys chemistry and one of the reasons is the practical work or the parents will say they really enjoyed the lesson when you…and cite a practical."*
>
> *Mixed, non-selective, state school (Year 3 of the study)*
>
> *"It is more of a hands-on subject. Whereas maths and English they are just sitting down all lesson. […] I heard a couple of the year 11s who are going into sixth form going oh yeah, I want to do science because we get to do practicals."*
>
> *Mixed, non-selective, state school (Year 3 of the study)*
>
> *"Higher up the school I noticed with my year 12s in particular, [that] I have some students that love the practical aspect and they are not necessarily the students that are very strong academically… They start to realise whether it is their strength and whether they should be going into a job that has practical work involved or whether they should be going in to something more academic."*
>
> *Mixed, non-selective, state school (Year 2 of the study)*

8.2.1.3 Preparing for practical work assessment

Average number of hours spent preparing for and carrying out statutory practical assessment

In the 14 – 16 age range little variation between subjects or between state (10 to 14 hours) and independent schools (6 to 9 hours) (Table 15) was reported in the number of hours spent preparing for and carrying out statutory practical assessment. In physics, state schools reported that they spent on average 5 hours per year more than independent schools preparing for and carrying out statutory practical assessment. In the post – 16 age range, students in state schools were reported to spend between 14 and 22 hours per year preparing for and carrying out statutory practical work (Table 16). In independent schools this figure was 14 to 21 hours. Over the course of the study, an increase in the number of hours spent preparing for and carrying out statutory practical assessment was reported for biology in state schools in both the 14 – 16 and post – 16 age ranges. Chemistry in independent schools also showed an increase year on year. In Scotland, figures are for all science subjects combined (Table 17). In year 3 of the study, post – 16 students spent more time preparing for and carrying out statutory practical assessment than students in the 14 – 16 age.

Data for the 11 – 14 age range in England and Scotland are not shown as there is no statutory practical assessment in this age range.

In year 3 of the study, heads of science and science teachers were asked whether they were teaching a GCSE syllabus to their year 9 (13 - 14 year old) students (i.e. that they were beginning teaching the curriculum early, leading to an extended period over which to cover the GCSE material). In English state schools, 98 of 112 respondents (88%) answered that they were teaching GCSE to their year 9 students; fewer than 10 were teaching IGCSE[8]. This figure is higher than the one-third of schools reported by the Department for Education (2018) to have started teaching a GCSE in year 9. In English independent schools, 42 out of 52 (81%) respondents reported they were teaching a GCSE syllabus. Of these, 24 were teaching IGCSE.

Table 15. 14 – 16 age range (England): Average number of hours spent preparing for and carrying out statutory practical assessment per academic year, over the three years of the study and between subjects. Respondents were heads of science and science teachers. 95% confidence intervals are indicated in brackets. Statistically significant rates of change per year are highlighted in bold with the level of significance stated below the table.

	Year 1		Year 2		Year 3		Rate of change per year
	n	Hours	n	Hours	n	Hours	
Biology (state)	52	10 (12, 8)	71	12 (14, 10)	138	14 (16, 12)	**1.886***
Biology (independent)	28	8 (11, 5)	37	8 (11, 5)	43	8 (11, 5)	-0.084
Chemistry (state)	81	13 (15, 11)	91	14 (17, 11)	162	12 (14, 10)	-0.371
Chemistry (independent)	57	9 (12, 6)	49	8 (11, 5)	57	7 (10, 4)	-0.533
Physics (state)	64	10 (12, 8)	70	14 (17, 11)	133	13 (15, 11)	1.116
Physics (independent)	41	6 (9, 3)	52	8 (11, 5)	79	8 (10, 6)	0.599

***P<0.05**

[8] The IGCSE is an international qualification for 14 – 16 year old students, taught in English.

Table 16. Post – 16 age range (England): Average number of hours spent preparing for and carrying out statutory practical assessment per academic year, over the three years of the study and between subjects. Respondents were heads of science and science teachers teaching students. 95% confidence intervals are indicated in brackets. Statistically significant rates of change per year are highlighted in bold with the level of significance stated below the table

	Year 1		Year 2		Year 3		Rate of change per year
	n	Hours	n	Hours	n	Hours	
Biology (state)	64	14 (16, 12)	71	20 (23, 17)	106	22 (25, 19)	**3.533***
Biology (independent)	26	17 (24, 10)	36	19 (25, 13)	50	20 (24, 16)	1.209
Chemistry (state)	78	19 (23, 15)	85	17 (20, 14)	137	17 (19, 15)	0.013
Chemistry (independent)	55	14 (17, 11)	49	17 (21, 13)	55	20 (24, 16)	**2.650***
Physics (state)	60	16 (19, 13)	61	19 (22, 16)	109	20 (22, 18)	1.674
Physics (independent)	39	19 (24, 14)	54	16 (19, 13)	76	21 (25, 17)	1.407

***P<0.05**

Table 17. All subjects combined (Scotland): Average number of hours spent preparing for and carrying out statutory practical assessment per academic year over each of the three survey years showing data for 11 – 14 age range (n = 74), 14 – 16 age range (n = 112) and post – 16 age range (n = 113). Respondents were heads of science and science teachers. 95% confidence intervals are indicated in brackets. Statistically significant rates of change per year are highlighted in bold with the level of significance stated below the table.

	Year 1		Year 2		Year 3		Rate of change per year
	n	Hours	n	Hours	n	Hours	
14 – 16 age range							
All subjects (state)	19	12 (19, 5)	38	9 (12, 6)	55	8 (10, 6)	-1.979
Post – 16 age range							
All subjects (state)	20	15 (22, 8)	36	13 (16, 10)	57	14 (17, 11)	-0.387

Telephone interviews with heads of science and science teachers in Scotland indicated that the introduction of assignments (detailed investigations) to National 5 and Higher courses had led to increased rigour and upskilling of teachers (to act as external examiners) to ensure students were not disadvantaged within the practical work elements of their qualifications.

8.2.2 Technical support, facilities and budgets

This section considers the sufficiency of facilities within schools for supporting the delivery of high quality practical work. Factors considered include: technical support; laboratory facilities; preparation room facilities; availability of science equipment; heads of science's satisfaction with factors affecting the delivery of high quality practical work; and science budget.

Key findings:

Technical support

Technical support in schools was significantly different between state and independent schools in England (for both mean number of FTE technicians per school and mean number of FTE technicians per 100 pupils in each year of the study). Respondents from English state schools reported an average over the three years of the study of 2.5 – 2.6 FTE technicians per school equating to 0.23 – 0.26 FTE technicians per 100 pupils. In independent schools, respondents indicated that they were supported by 2.9 – 3.1 FTE technicians with an average of 0.48 – 0.53 FTE technicians per 100 pupils. Respondents from Scotland reported having an average of 1.0 and 1.5 FTE technicians with an average of 0.16 – 0.19 FTE technicians per 100 pupils.

There was no change observed in the reported number of FTE technicians per school over the 3 years of the study. However, when asked in year 3 of the study to indicate whether technical support had increased, decreased or remained the same since the previous year, heads of science in 26% of state schools in England, 10% of independent schools in England and 24% of Scottish state schools reported that there had been a decrease - the main reason for this was said to be financial. English state schools had the highest percentage of respondents indicating at least one technician post unfilled within their school.

Over 70% of technician respondents from independent schools in England indicated that they were specialist science subject technicians. The opposite was observed in state schools in England (over 66% being general science technicians).

Between 62% and 69% of heads of science from state schools in England indicated that they were satisfied or very satisfied with the sufficiency of technical support within their school, with 21% to 25% of respondents in each year of the study reporting that they were dissatisfied or very dissatisfied with the level of technical support. Between 68% and 81% of respondents from independent schools in England reported that they were satisfied or very satisfied with the level of technical support within their school with 7% to 13% reporting being dissatisfied or very dissatisfied across the three years.

In all years of the study, for both state and independent schools in England, there was a positive correlation between the heads of science's satisfaction with sufficiency of technical support and the number of FTE technicians within their school. In independent schools in England in all three years of the study, there was also a negative correlation between heads of science's satisfaction with the sufficiency of technical support and the number of pupils per FTE technician in their school i.e. the higher the number of pupils per FTE technician, the lower the level of satisfaction with the sufficiency of technical support.

In both state and independent schools in England and state schools in Scotland, setting up equipment for an experiment was the task that the highest number of technicians reported carrying out on a daily basis.

Facilities

The majority of technicians reported that basic laboratory facilities were generally available. In both state schools in England and Scotland and independent schools in England in years 1 and 3 of the study, over 50% of respondents indicated that only a few, or none, of their laboratories had computers available for student use. In year 3 of the study 79% of respondents from state schools in England and 71% from independent schools in England and state schools in Scotland reported most or all of their laboratories were accessible to Special Educational Needs and Disability (SEND) students.

The average number of preparation rooms per school was reported to be 2.3 – 2.4 in state schools in England, 3.1 – 3.6 in independent schools and 1.8 in Scotland.

Respondents from independent schools in England stated that 62% - 63% of their preparation rooms were subject specific while state schools in England showed the opposite (58% - 65% of respondents stating that preparation rooms were shared between all sciences). In Scotland, 80% of respondents stated that their preparation rooms were shared between all sciences.

State schools in England reported an average ratio of 4.5 laboratories per preparation room, independent schools in England reported an average ratio of 3.0 – 3.6 laboratories per preparation room and state schools in Scotland reported an average ratio of 7.2 laboratories per preparation room.

Budget

Respondents from state schools in England reported that their mean budget was £11 - £12 per pupil per academic year across the three years of the study. In independent schools the mean budget was £33 to £37 per pupil per year. In Scotland, the mean science budget per pupil per academic year was between £4 and £6 over the three years of the study. It is important to note that the way that budgets are allocated within school was not asked as part of the survey and this may account for differences in observed budgets between school types and nations.

On average, heads of science from independent schools in England had a significantly higher level of satisfaction than respondents from state schools in England as to whether their department had sufficient budget to carry out high quality practical work.

Satisfaction with teacher competency, technical support, facilities and budget

Heads of science were asked to rate their satisfaction across six areas. Respondents from state and independent schools in England and state schools in Scotland reported that the factor they were most satisfied with was their teachers having sufficient competency to carry out high quality practical work. Heads of science in state schools in England and Scotland were least satisfied that their department had a sufficient budget to carry out high quality practical work. Heads of science from independent schools were least satisfied with the department having sufficient laboratory facilities to carry out high quality practical work. A decrease in heads of sciences' average level of satisfaction with the sufficiency of laboratory facilities in their department was observed in independent schools in England over the period of the study.

8.2.2.1 Technical support

Number of full time equivalent (FTE) technicians supporting science within schools

State schools in England reported employing between 0 and 12 Full Time Equivalent (FTE) technicians, with an average of 2.5 – 2.6 FTE technicians across the three years of the study (Table 18). Respondents from independent schools in England reported having between 0 and 8 FTE technicians, with a higher average than state schools of 2.9 – 3.1 FTE technicians per school. In Scotland, respondents reported having between 0 and 3 FTE technicians, with an average of between 1.0 and 1.5 FTE technicians across the period of the study. Figure 73 in Appendix 3 and Table 33 in Appendix 3 and shows the frequency of reported numbers of FTE technicians.

Analysing the data by school size identifies a positive relationship in both state and independent schools in England and Scotland between the number of technicians and number of pupils within a school (Table 34 in Appendix 3).

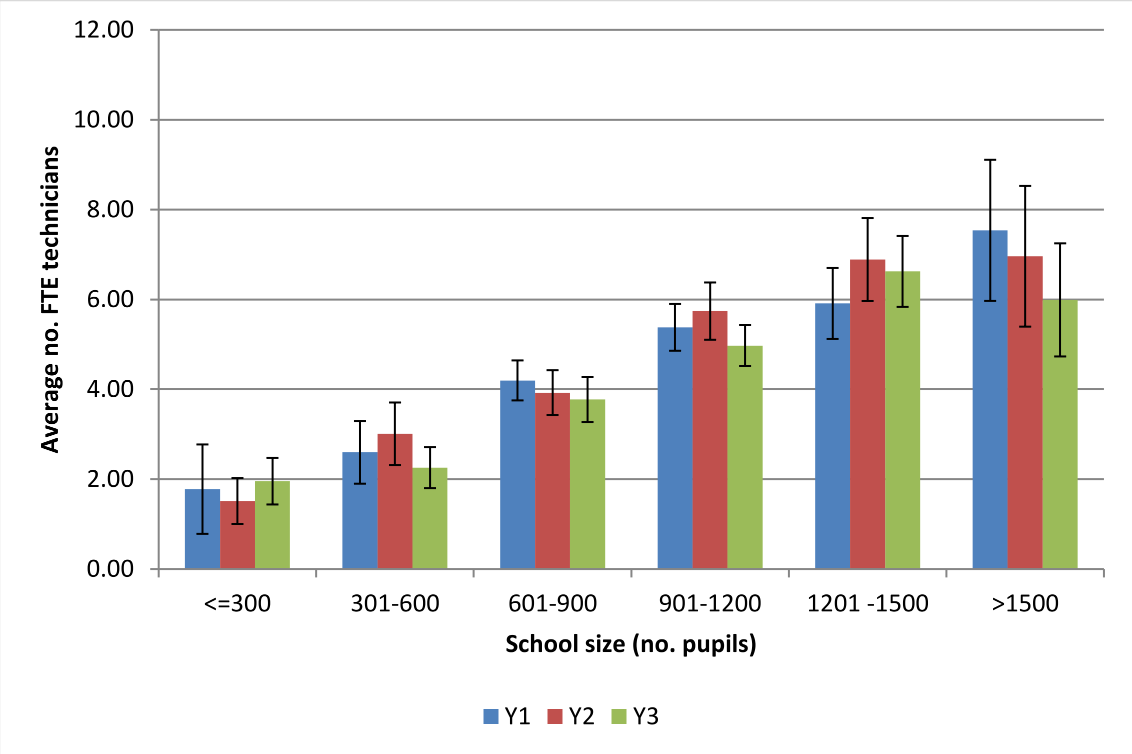
The average number of FTE technicians per 100 pupils was lower in state schools in England than independent schools with 0.23 - 0.26 in state schools and 0.48 – 0.53 in independent schools across the three years of the study (Table 19). In Scotland the average number of FTE technicians per 100 pupils was 0.16 – 0.19 across the three years of the study.

Table 18. (England and Scotland) Mean number of FTE technicians within schools over the three years of the study. Respondents were heads of science.

	Year 1		Year 2		Year 3		Rate of change per year
	n	Mean no. FTE technicians	n	Mean no. FTE technicians	n	Mean no. FTE technicians	
England state	149	2.5 (2.3,2.7)	129	2.6 (2.4,2.9)	156	2.5 (2.2,2.8)	-0.024
England independent	92	3.1 (2.7,3.4)	80	3.0 (2.6,3.4)	72	2.9 (2.5,3.3)	0.137
Scotland	17	1.0 (0.7,1.3)	17	1.5 (1.2,1.8)	21	1.5 (1.1,1.8)	0.216

Figure 34. (England): Histogram showing the number of FTE technicians by school size over the three years of the study in a) state schools and b) independent schools. Respondents were heads of science. 95% confidence intervals are indicated on the graph.

a) State schools (base n = 429)



b) Independent schools (base n = 244)

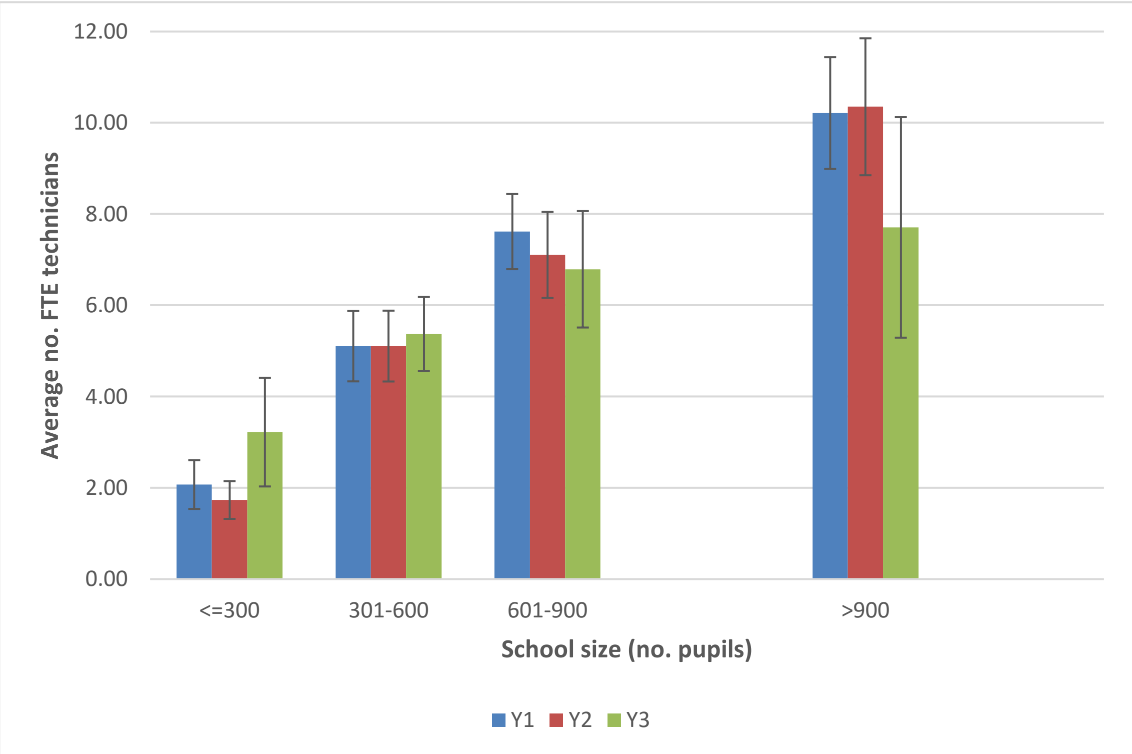


Table 19. (England and Scotland) Mean number of FTE technicians per 100 pupils within schools over the three years of the study. Respondents were heads of science.

	Year 1	Year 2	Year 3	Rate of change per year
	Mean no. of technicians per 100 pupils	Mean no. of technicians per 100 pupils	Mean no. of technicians per 100 pupils	
England state	0.24 (0.22, 0.26)	0.26 (0.23, 0.29)	0.23 (0.21, 0.25)	-0.01
England independent	0.53 (0.47, 0.58)	0.48 (0.44, 0.53)	0.52 (0.46, 0.59)	0.00
Scotland	0.18 (0.14, 0.22)	0.19 (0.15, 0.23)	0.16 (0.13, 0.18)	-0.01

In year 3 of the study, heads of science were asked to report whether there had been a change in the number of technicians (FTE) in their schools within the last year (Table 20). In all three school types, the majority of respondents reported that the number of FTE technicians had remained the same. This is consistent with the findings in Table 18 where no change was observed in the reported number of FTE technicians in schools over the three years of the study.

Respondents reporting a change in provision were asked to select the reasons for the change from a list (respondents were able to select more than one reason). Of the respondents from state schools in England who reported a decrease in the number of technicians; 46% selected ‘financial’, 21% selected ‘decision not to recruit after the position became vacant’ and 11% selected ‘school restructuring’. To preserve the anonymity of respondents, the breakdown of reasons from independent schools in England and state schools in Scotland cannot be reported.

Table 20.(England and Scotland) Heads of science reporting on whether the number of FTE technicians has changed within the school between year 2 and year 3 of the study.

	England state	England independent	Scotland
	%	%	%
Increased	3	9	0
Decreased	26	10	24
Stayed the same	72	81	76

Unfilled technician positions

Across the three years of the study, between 9% and 11% of respondents from English state schools indicated that there was at least one technician position unfilled within their school. The figure was between 1% and 4% in English independent schools and between 0% and 17% in Scottish state schools.

Specialism of technicians

Technicians were asked to report whether they worked as a general (working across all sciences) or specialist (supporting a specific science subject) science technician (Table 21). A clear difference was observed between state and independent schools. Across the period of the study 70% - 74% of respondents from independent schools indicated that they were specialist science subject technicians and 26% - 30%, that they were general science technicians. The opposite was observed in state schools in England with 66% - 68% indicating general science technicians and 32% - 34% specialist technicians. A breakdown of the data cannot be provided for Scotland to preserve the anonymity of respondents.

Table 21. (England) Technicians reporting if they are employed in a general (all sciences) or specialist (a specific science subject) capacity.

School and technician type	Year 1		Year 3	
England state schools	**n**	**%**	**n**	**%**
General science technician	144	68	604	66
Specialist science subject technician	67	32	314	34
Total	**211**		**919**	
England independent schools				
General science technician	12	30	62	26
Specialist science subject technician	27	70	177	74
Total	**39**		**239**	

Table 22. (England and Scotland) Subjects supported by respondents indicating they were specialist science technicians. Respondents could select more than one option.

School type and subject	Year 1		Year 3	
	n	**%**	**n**	**%**
England state schools				
Biology	26	32	134	35
Chemistry	30	37	156	40
Physics	26	32	97	25
Total	**82**	**100**	**387**	**100**
England independent schools				
Biology	11	39	62	33
Chemistry	7	25	69	36
Physics	10	36	59	31
Total	**28**	**100**	**190**	**100**

Perception of sufficiency of technical support

In all three years of the study in English state schools, between 62% and 69% of heads of science indicated that they were satisfied or very satisfied with the sufficiency of technical support within their school (Figure 35 below and Table 35 in Appendix 3). However, 21% to 25% of respondents in each year of the study reported that they were dissatisfied or very dissatisfied with the sufficiency of technical support. Between 68% and 81% of respondents from independent schools in England reported that they were satisfied or very satisfied with the level of technical support within their school (Figure 35 and Table 35 in Appendix 3). Between 7% and 13% reported being dissatisfied or very dissatisfied across the three years.

In all years of the study for both state and independent schools in England, there was a positive correlation between heads of science's satisfaction with sufficiency of technical support and the number of FTE technicians within their school i.e. heads of science with a greater number of FTE technicians were more satisfied with the level of support (Table 23). In independent schools in England there was also a significant negative correlation between heads of science's satisfaction with the sufficiency of technical support and number of pupils per FTE technicians in their school in all three years of the study (i.e. more pupils per FTE technician was associated with lower satisfaction) (Table 24).

There were too few respondents from Scotland to reliably report the findings for heads of science's satisfaction with the level of technical support within their school.

Figure 35. (England) Bar chart showing heads of science satisfaction with sufficiency of technical support in the three years of the study. Respondents were heads of science.

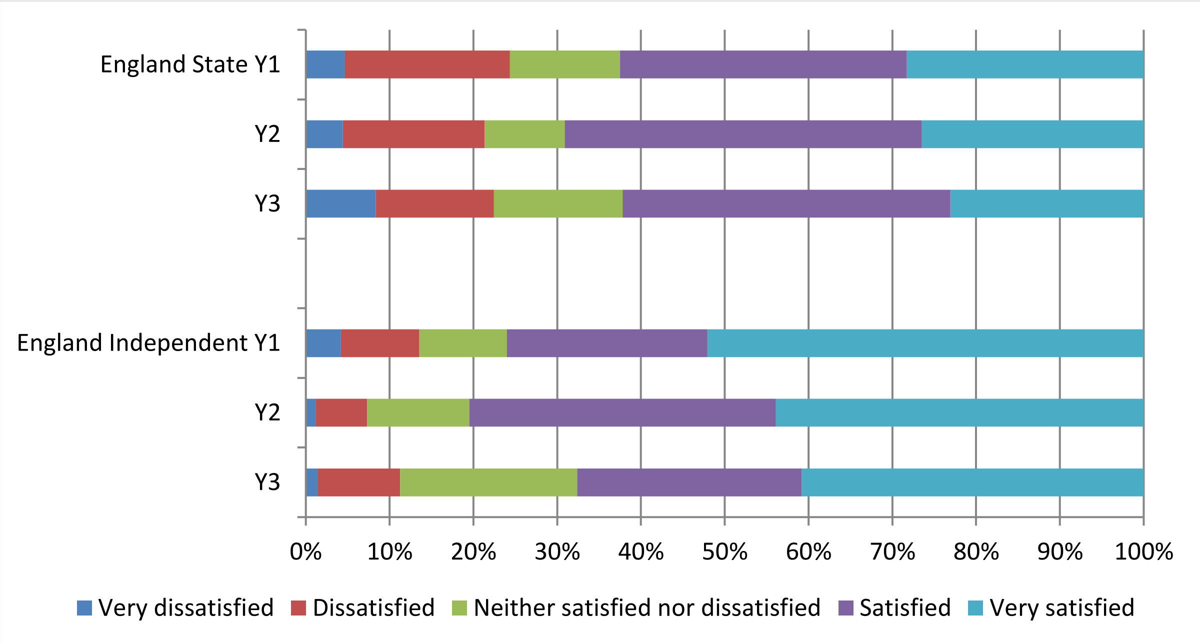


Table 23. (England) Correlation between heads of science's satisfaction with sufficiency of technical support in the three years of the study and the number of FTE technicians within the respondents' school. Respondents were heads of science. Statistically significant correlations are highlighted in bold with the level of significance stated below the table.

	Year 1		Year 2		Year 3	
	n	Correlation	n	Correlation	n	Correlation
England state	147	**0.42***	131	**0.30***	156	**0.20***
England independent	94	**0.45***	81	**0.37****	72	**0.29***

***P<0.01** ****P<0.05**

Table 24. (England) Correlation between heads of science satisfaction with sufficiency of technical support in the three years of the study and number of pupils per FTE technicians within the respondents' school. Respondents were heads of science. Statistically significant correlations are highlighted in bold with the level of significance stated below the table.

	Year 1		**Year 2**		**Year 3**	
	n	**Correlation**	**n**	**Correlation**	**n**	**Correlation**
England state	140	0.029	124	0.021	152	-0.017
England independent	88	**-0.260***	76	**-0.293***	69	**-0.245***

***P<0.05**

Tasks undertaken by technicians

Technicians were asked to state the frequency with which they undertook particular tasks within their role (the tasks are listed in Figure 36 to Figure 38 below and Table 36 in Appendix 3 to Table 38 in Appendix 3). In both state and independent schools in England and state schools in Scotland, setting up equipment for an experiment was the task that the highest number of respondents reported carrying out on a daily basis. There were too few respondents to report results for year 1 of the study in Scotland.

Other activities that more than half of technicians in state schools in England reported carrying out on a daily or weekly basis were: advising a teacher how to do an experiment/how to use equipment; photocopying worksheets for lessons; discussing science curriculum requirements with a teacher; moving furniture or textbooks. In independent schools in England and state schools in Scotland, the only task other than setting up equipment that more than half of technicians reported carrying out on a daily or weekly basis was advising a teacher how to do an experiment/how to use equipment.

More than half of respondents from all school types reported that they never set up general IT equipment.

In the qualitative focus groups in year 3 of the study, technicians were given the opportunity to give examples of the tasks in addition to the quantitative survey questions. Additional tasks that were reported included: purchasing consumables and taking care of waste; helping organize science events in school; and overseeing health and safety.

Example – Tasks undertaken by technicians

Participants in the focus groups in year 3 of the study provided addition detail about the types of task technicians undertook within their schools.

> *"I am responsible for the consumables, so ordering everything and making sure we have everything in place and the equipment for the practicals are running. Servicing [equipment] as they are going on and dismantle them. Get rid of the waste which is huge here and maintain things like administration tasks…so things going over to reprographics…I don't think we do anything over and above any other technician but it is just on a huge scale to maybe other schools and colleges. Some of the practicals can generate 60-100 litres of waste that I need to sort and deal with."*
>
> *Mixed, non-selective, state school (Year 3 of the study)*
>
> *"[Technicians] can expand their role and we certainly get them to help with the science week and it's women in engineering day tomorrow and there is organising trips and all sorts."*
>
> *Mixed, non-selective, state school (Year 3 of the study)*
>
> *"Science week - it is the technicians who organise it."*
>
> *Mixed, non-selective, state school (Year 3 of the study)*

__Figure 36. (England – state schools): Stacked bar chart showing the frequency with which technicians undertook different tasks within their role in years 1 and 3 of the study (base n = 13099). The final two tasks listed were only surveyed in year 3 of the study. Respondents were technicians.__

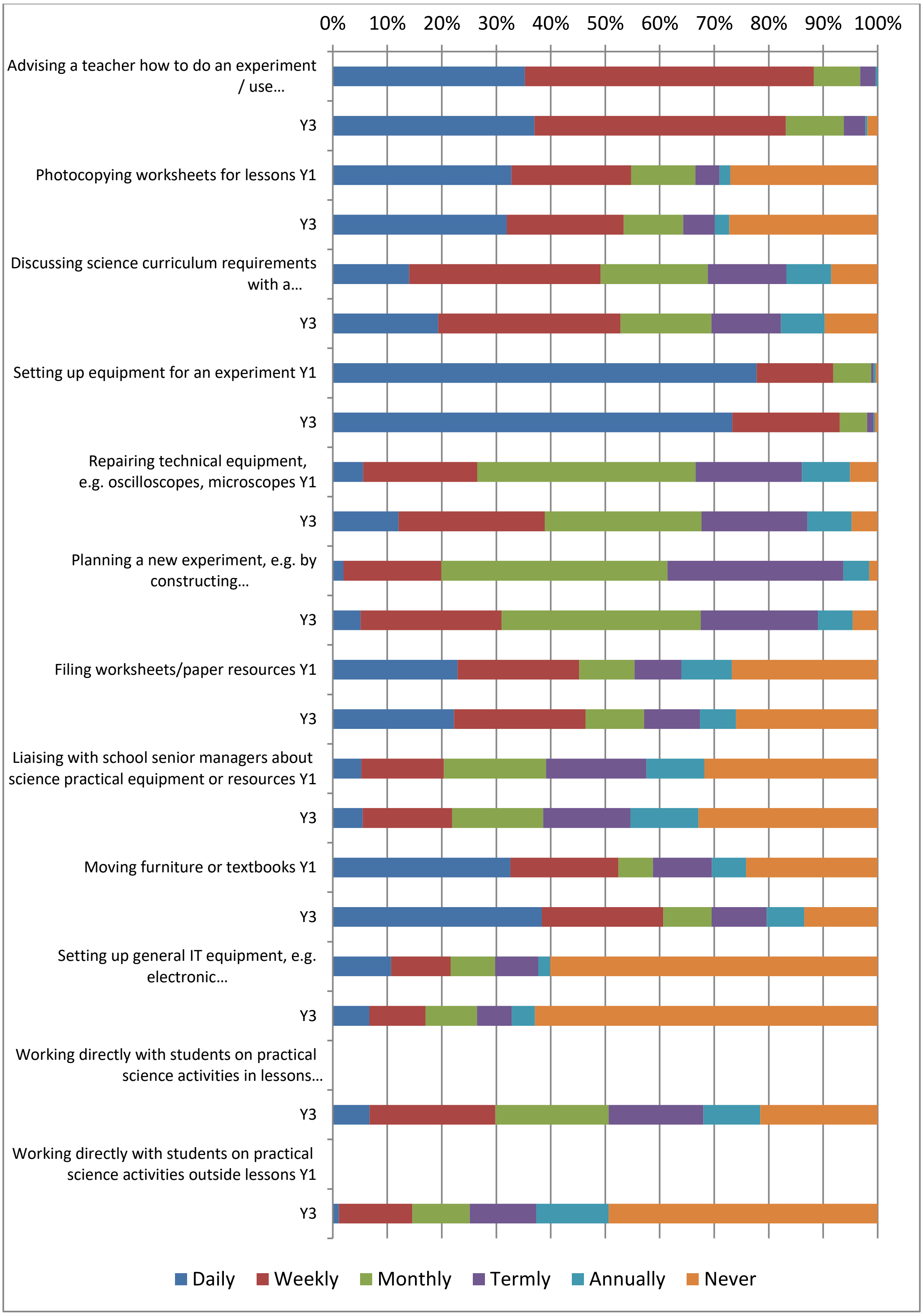


Figure 37. (England – independent schools): Stacked bar chart showing the frequency with which technicians undertook different tasks within their role in years 1 and 3 of the study (base n = 3235). The final two tasks listed were only surveyed in year 3 of the study. Respondents were technicians.

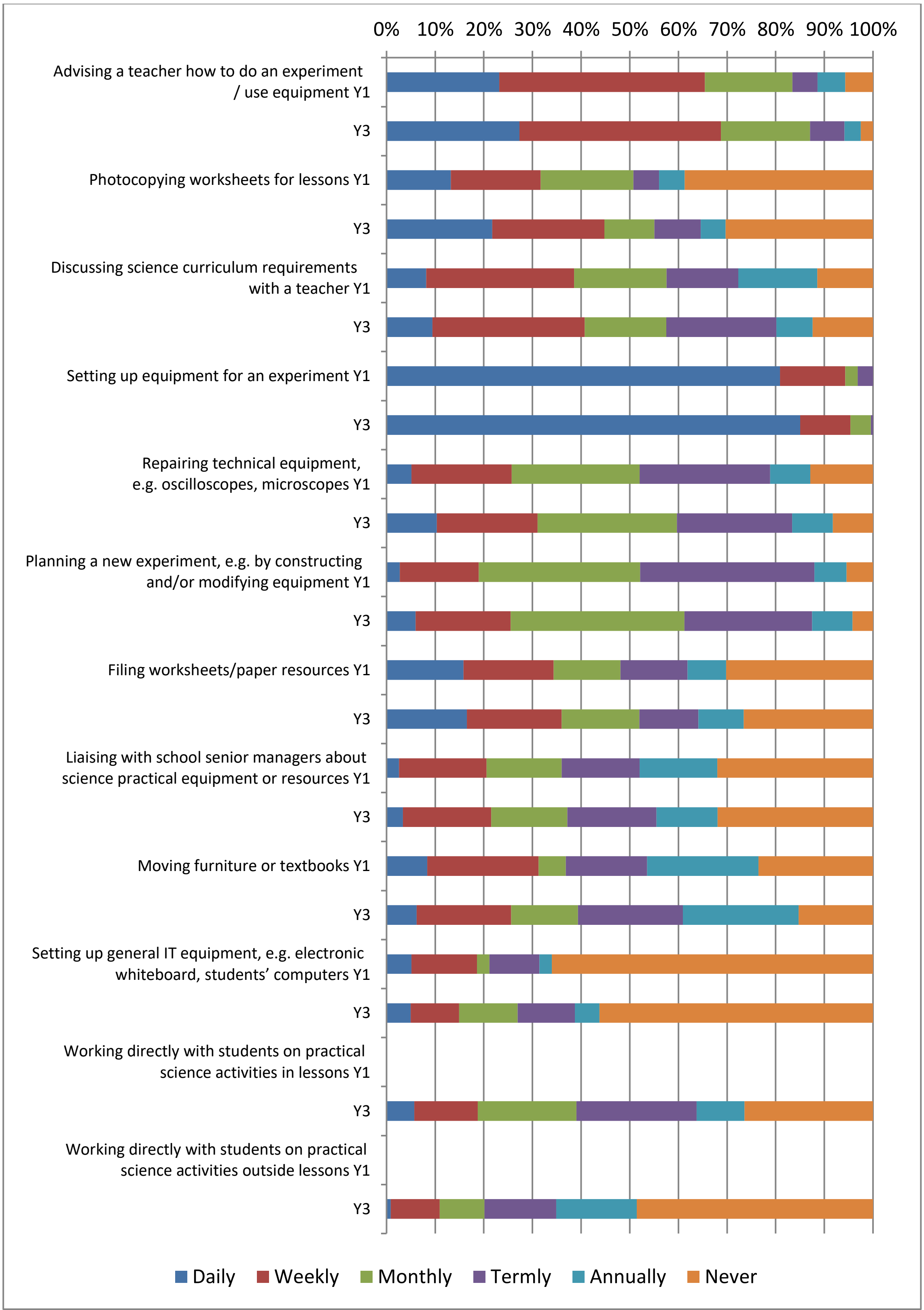
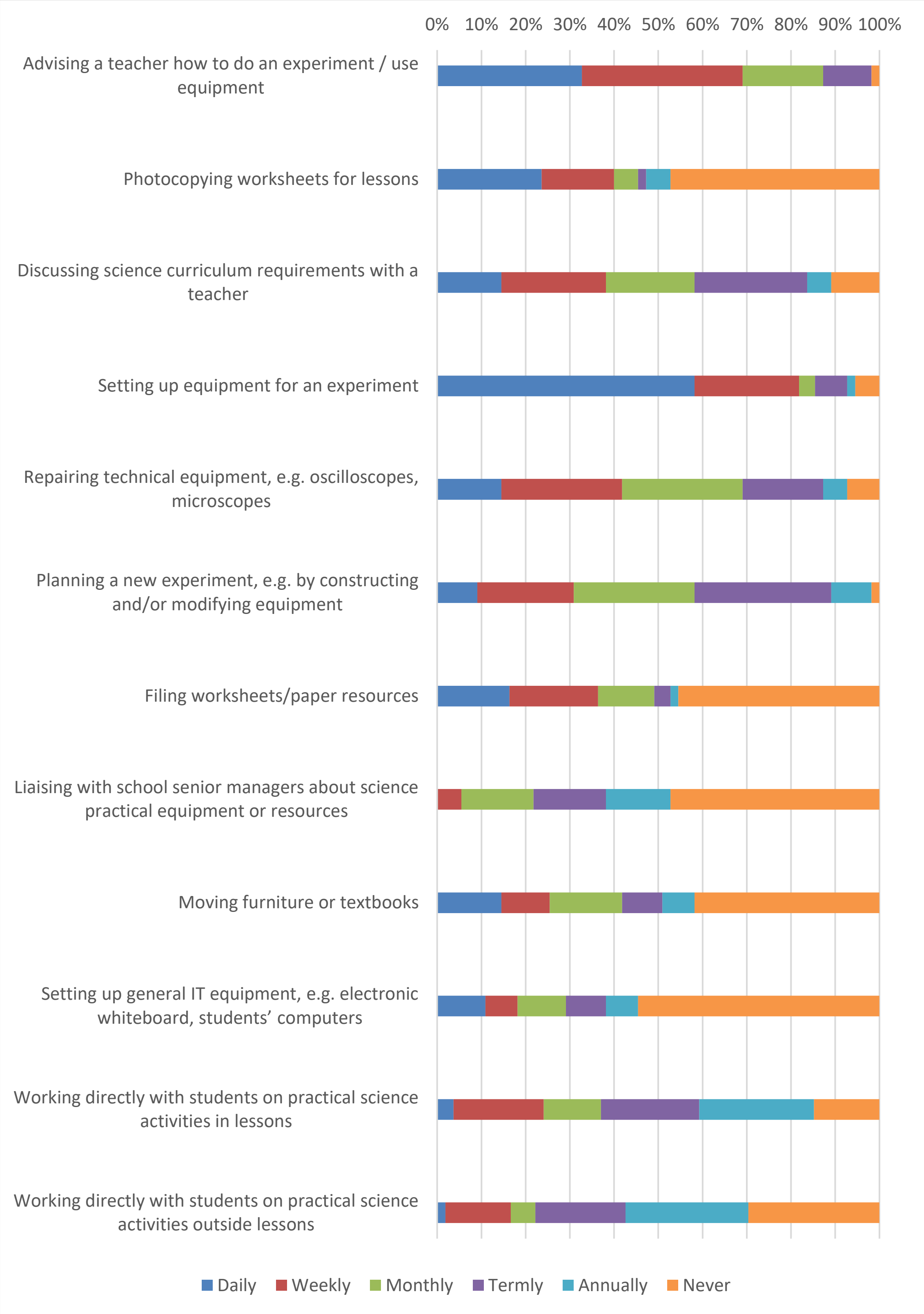


Figure 38. (Scotland – year 3 only): Stacked bar chart showing the frequency with which technicians undertook different tasks within their role in years 1 and 3 of the study (base n = 658). Respondents were technicians.



8.2.2.2 Equipment and consumables

Laboratory facilities

Table 25 shows the average number of laboratories per school (data collected in years 1 and 3 of the study) and a summary of the number of pupils per laboratory (year 3 only).

Table 25. (England and Scotland): Average number of laboratories in schools in years 1 and 3 of the study. Number of pupils per laboratory in respondents' schools in year 3 of the study. Respondents were technicians. 95% Confidence intervals are indicated in brackets.

	Year 1		Year 3			
	n	Mean number of laboratories	n	Mean number of laboratories	n	Mean number of pupils per laboratory
England state schools	212	8.2 (7.8, 8.7)	844	8.4 (8.1, 8.8)	842	205 (178,231)
England independent schools	39	8.7 (7.3, 10.0)	226	9.7 (9.2, 10.3)	226	97 (78,116)
Scotland state schools	-	-	51	9.5 (8.6, 10.3)	51	103 (79, 127)

When combined with school size information, state schools in England reported an average of 205 pupils per laboratory, while independent schools in England reported an average of 97 and state schools in Scotland reported an average of 103. The difference between state schools in England and independent schools in England was significant, but the difference between state schools in England and in Scotland was not.

Technicians were asked to evaluate the extent to which satisfactory (available and in good working order) facilities were available in laboratories within their school. Figure 39 to Figure 41 (and Table 39 in Appendix 3 to Table 41 in Appendix 3) provide a breakdown of the detail.

A majority of technicians reported that basic laboratory facilities were generally available. However, in both state schools in England and Scotland and independent schools in England in years 1 and 3 of the study, over 50% of respondents indicated that only a few, or none, of their laboratories had computers available for student use. In year 3 of the study, respondents provided information about accessibility for SEND students: 79% of respondents from state schools in England, 71% of respondents from independent schools in England and 71% of respondents from state schools in Scotland reported most or all of their laboratories were accessible to SEND students.

Figure 39. (England – state schools): Stacked bar chart showing technicians' evaluation of the extent to which satisfactory (available and in good working order) facilities were available in laboratories in years 1 and 3 of the survey (base n = 20879). Respondents were technicians.

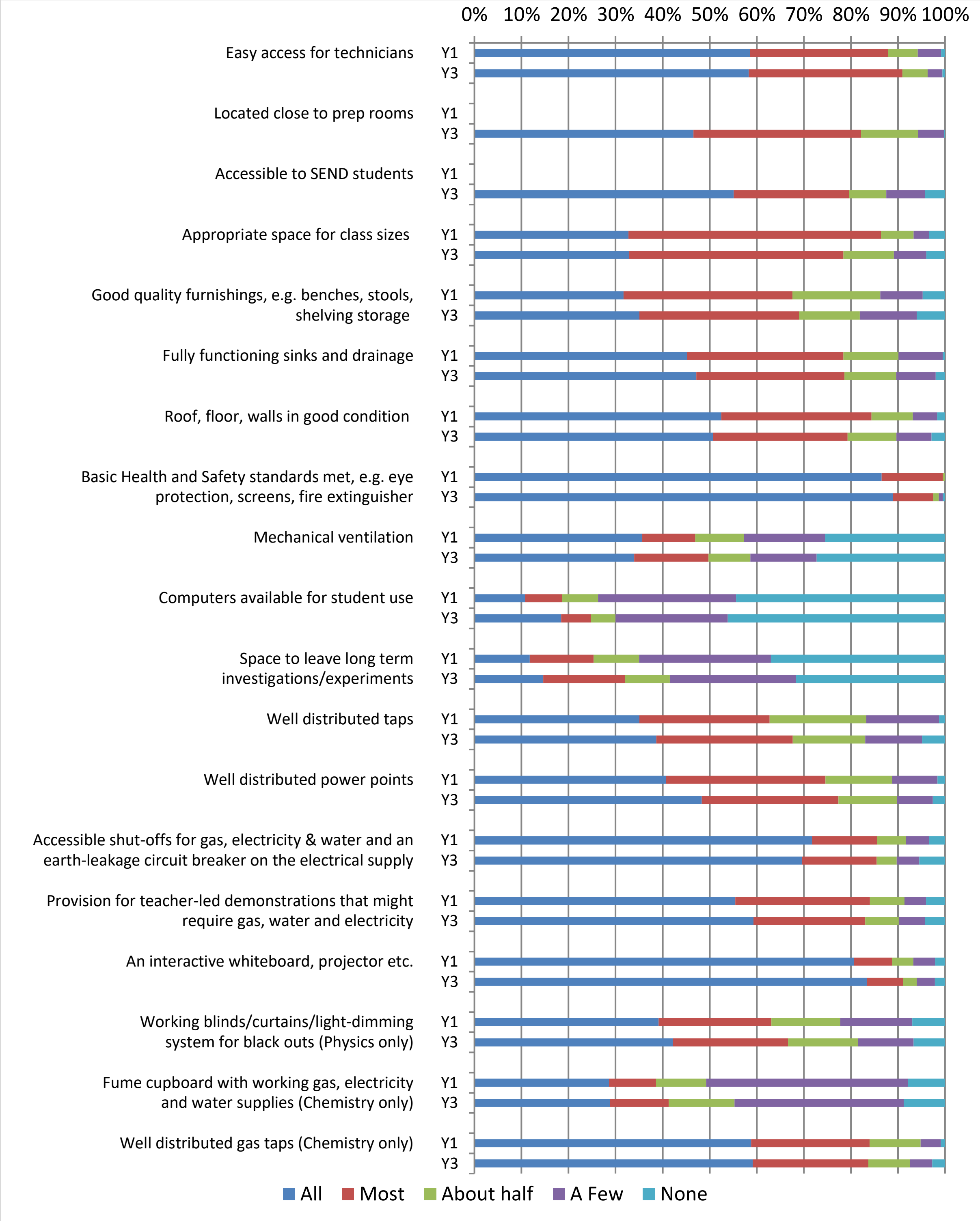


Figure 40. (England – independent schools): Stacked bar chart showing technicians' evaluation of the extent to which satisfactory (available and in good working order) facilities were available in laboratories in years 1 and 3 of the survey (base n = 5083). Respondents were technicians.

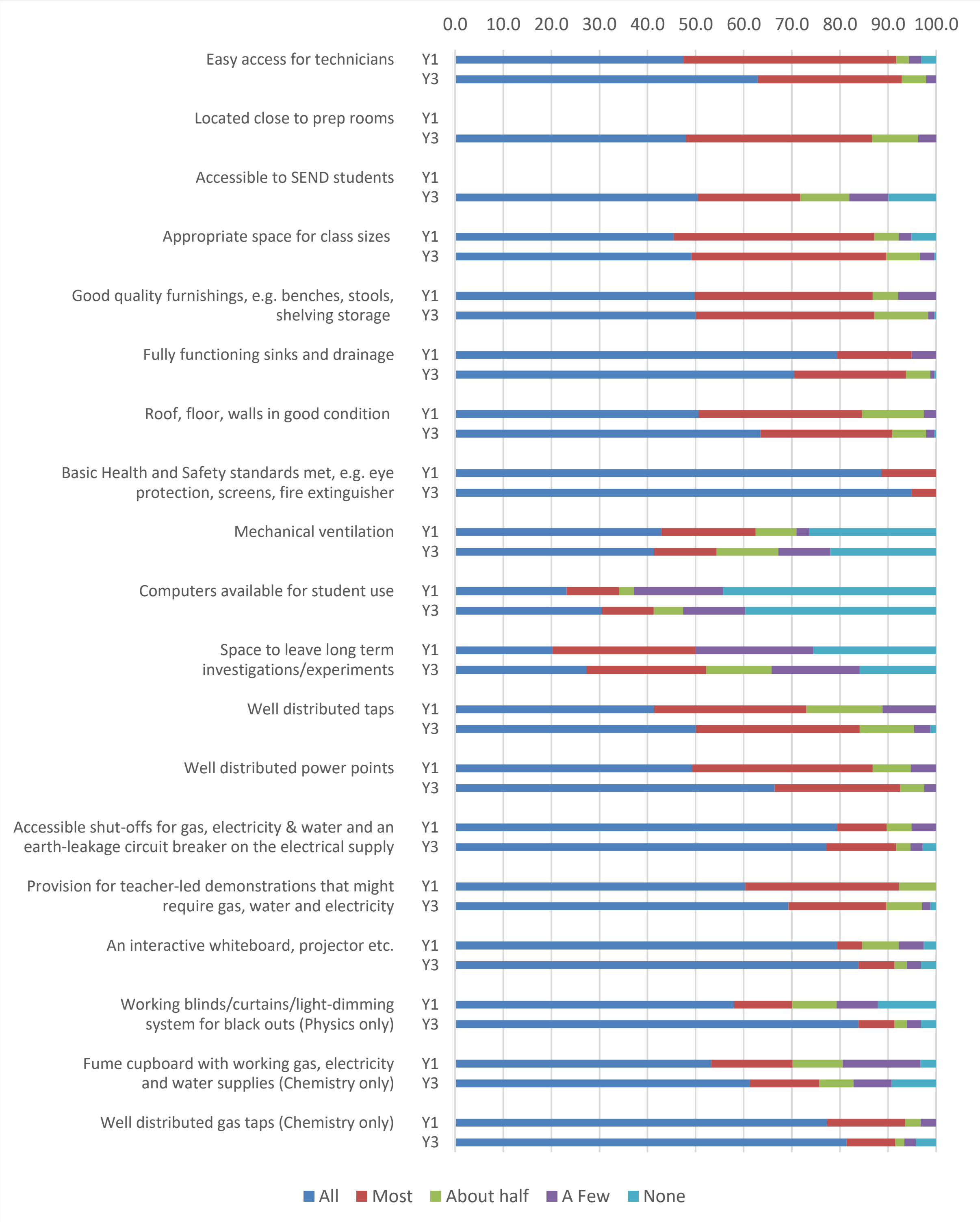
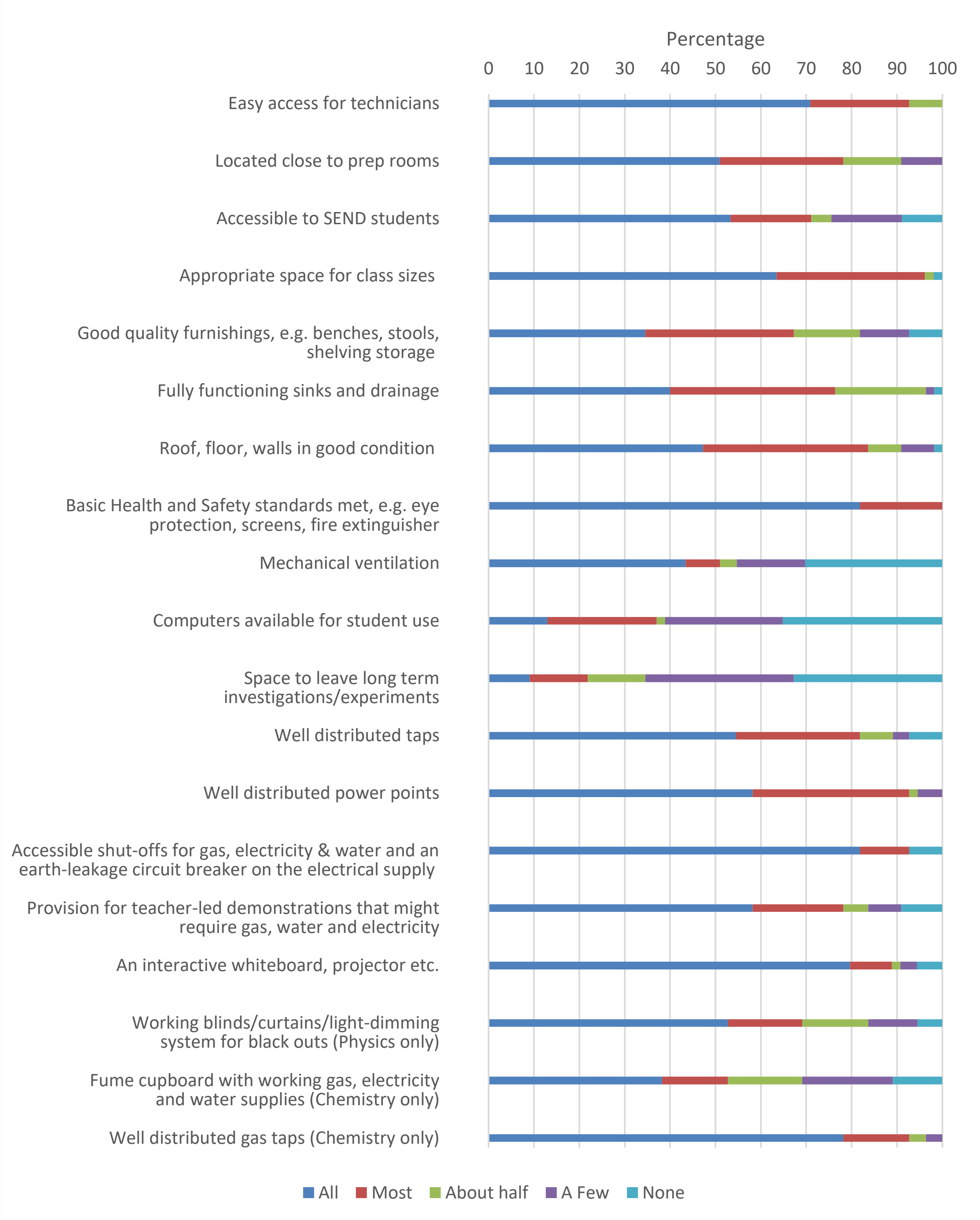


Figure 41. (Scotland – year 3 only): Stacked bar chart showing technicians' evaluation of the extent to which satisfactory (available and in good working order) facilities were available in laboratories (base n = 1028). Respondents were technicians.



Preparation rooms

Table 26 shows the number and type of preparation rooms per school as reported by technicians. The average number of preparation rooms per school was 2.3 – 2.4 in state schools in England, 3.1 – 3.6 in independent schools and 1.8 in Scotland. The type of preparation room aligns with the findings relating to technician specialism in state and independent schools, with 62% - 63% of respondents in independent schools stating subject specific preparation rooms, 58% - 65% shared between all sciences in state schools in England and 80% shared between all sciences in Scotland. The difference between state schools in England and independent schools in England was significant.

Table 26. (England and Scotland) Mean number and type of preparation rooms in respondents' schools in years 1 and 3 of the study. Respondents were technicians. 95% Confidence intervals are indicated in brackets.

School and preparation room type	Year 1 n	Year 1 Mean number of preparation rooms	Year 1 n	Year 1 %	Year 3 n	Year 3 Mean number of preparation rooms	Year 3 n	Year 3 %
England state schools								
Subject specific preparation rooms for biology, chemistry and physics	212	2.3 (2.1,2.5)	39	19	919	2.4 (2.3,2.5)	206	23
Preparation rooms are shared between all sciences			138	65			532	58
Both specialist and shared preparation rooms			35	16			176	19
England independent schools								
Subject specific preparation rooms for biology, chemistry and physics	39	3.6 (2.4,4.8)	24	62	239	3.1 (2.9,3.2)	152	63
Preparation rooms are shared between all sciences			9	23			48	20
Both specialist and shared preparation rooms			6	15			399	17
Scotland state schools								
Subject specific preparation rooms for biology, chemistry and physics	-	-	-	-	55	1.8 (1.3,2.3)	3	6
Preparation rooms are shared between all sciences			-	-			44	80
Both specialist and shared preparation rooms			-	-			8	15

Table 27 reports the ratio of laboratories to preparation rooms. State schools in England had a higher ratio of laboratories to preparation rooms than independent schools in England. The ratio of laboratories to preparation rooms was even higher in Scotland.

Figure 42 to Figure 44 (and Table 42 in Appendix 3 to Table 44 in Appendix 3) provide detail of technicians' evaluation of the availability and sufficiency of preparation room facilities in their schools.

Table 27. (England and Scotland) Ratio of laboratories to preparation rooms in respondents' in years 1 and 3 of the study. Respondents were technicians. 95% Confidence intervals are indicated in brackets.

	n	Ratio of laboratories to preparation rooms (year 1)	n	Ratio of laboratories to preparation rooms (year 3)
England state schools	212	4.5 (4.2, 4.8)	844	4.5 (4.3, 4.7)
England independent schools	39	3.0 (2.6, 3.5)	226	3.6 (3.4, 3.9)
Scotland state schools	-	-	51	7.2 (6.2, 8.3)

Figure 42. (England – state schools): Stacked bar chart showing technicians' evaluation of the factors and facilities of preparation rooms relevant within their school/college in years 1 and 3 of the survey (base n = 16147). Respondents were technicians.

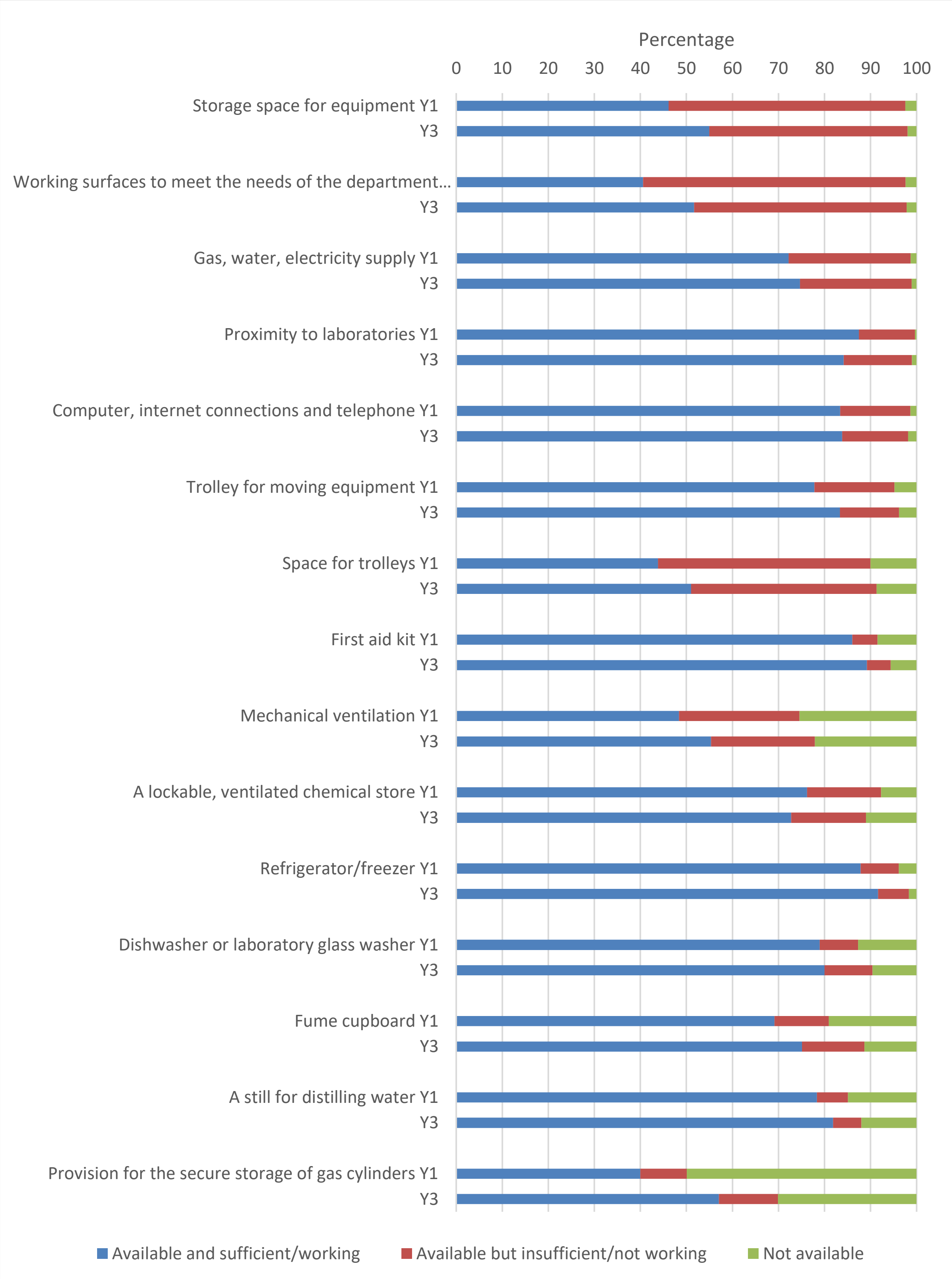


Figure 43. (England – independent schools): Stacked bar chart showing technicians' evaluation of the factors and facilities of preparation rooms relevant within their school/college in years 1 and 3 of the survey (base n = 3844). Respondents were technicians.

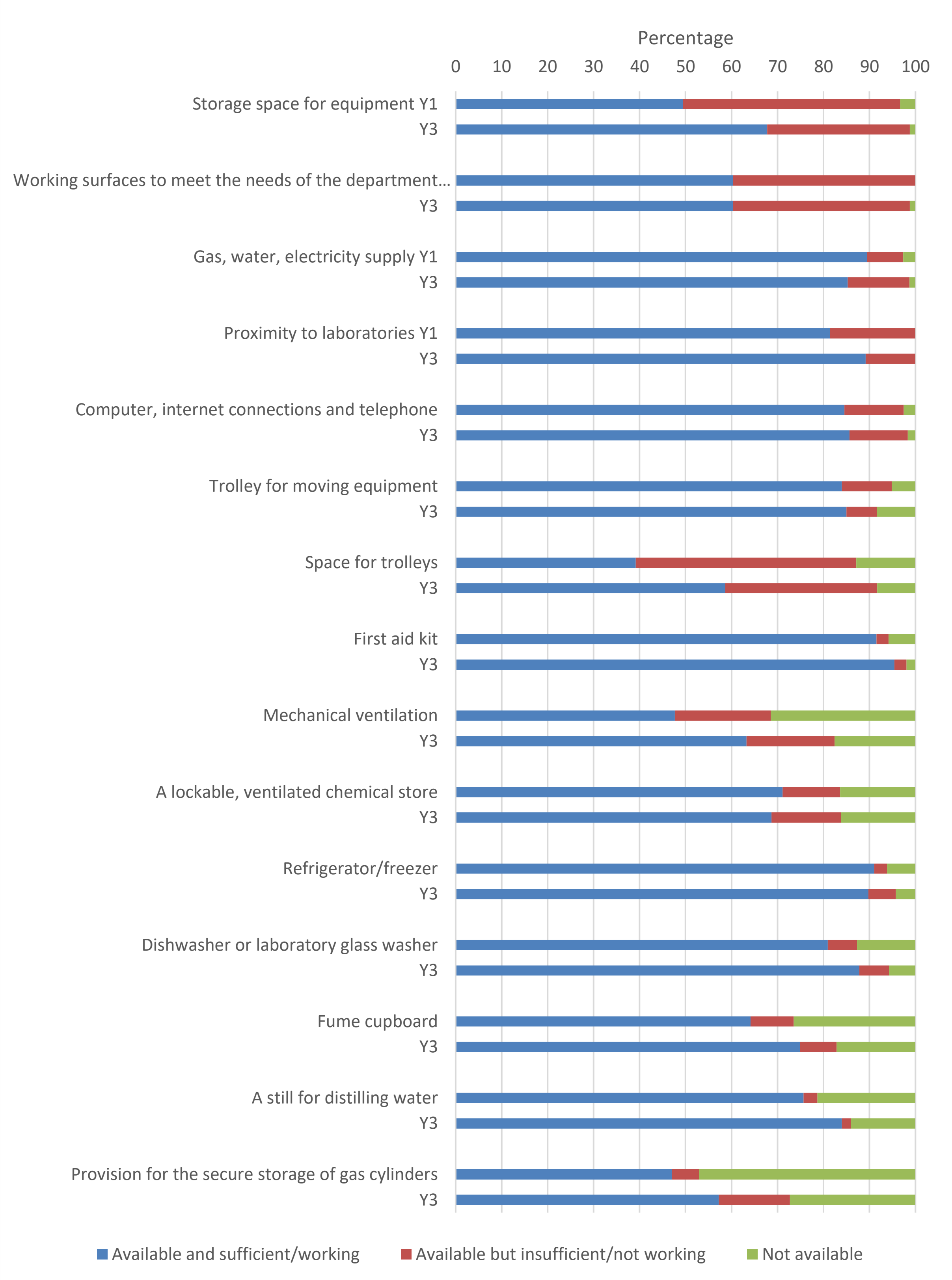
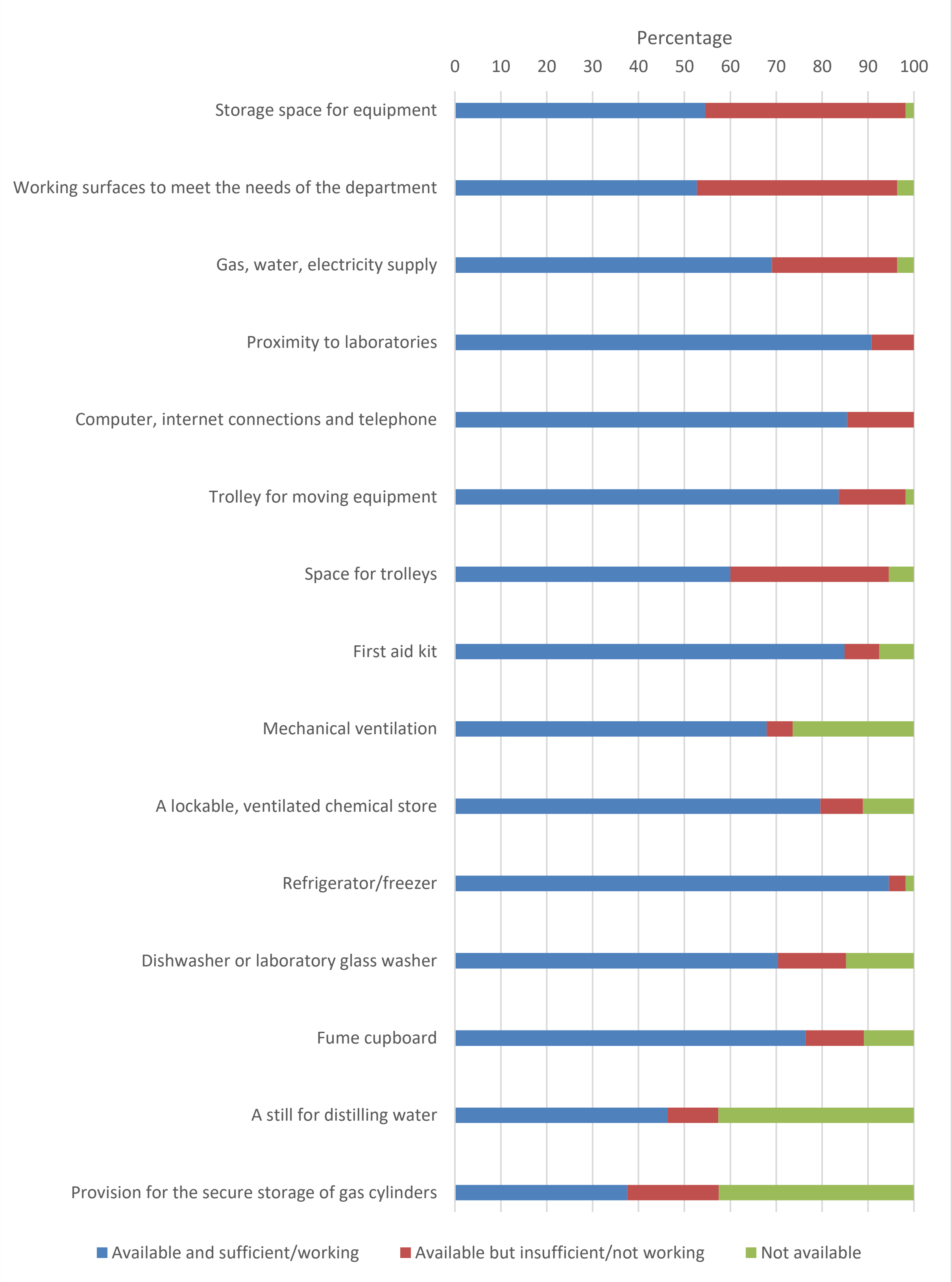


Figure 44. (Scotland – year 3 only): Stacked bar chart showing technicians' evaluation of the factors and facilities of preparation rooms relevant within their school/college in year 3 of the survey (base n = 919). Respondents were technicians.



<u>**Availability of science equipment**</u>

Figure 45 to Figure 53 (and Table 45 in Appendix 3 to Table 53 in Appendix 3) show the detailed breakdown of technicians' evaluation of subject-specific and general science equipment in years 1 and 3 of the study.

The majority of technicians indicated that their schools had access to basic science equipment. However, in both years 1 and 3 of the study, 73% of respondents from state schools in England indicated that they did not have genetic engineering kits available in the school for teaching biology. Over 50% of respondents in both state and independent schools in England indicated that they did not have available a UV spectrophotometer for chemistry teaching and over 57% of respondents from state schools in England also reported that they did not have available a class sets of magnetic stirrers or class sets of heating mantles. There was no equipment that more than half of respondents reported was unavailable within their schools for teaching physics.

Schools reported a range of ways of sourcing equipment to support the new curriculum. However, some participants in focus groups and telephone interviews raised concerns that not all schools may be able to access equipment to provide all students with an equal opportunity to experience the practical work examples suggested by the exam boards. In general, more state schools than independent schools commented that it was necessary for students to share equipment.

Example: Access to equipment

In year 2 of the study, as schools transitioned into the new GCSE and A level curricula they explained some of the challenges of acquiring equipment to support the new practical work.

> *"[There are] new practical [experiments] which have been put in with rather expensive pieces of equipment… Ironically, about 4 years ago things got thrown away because they weren't used much and now suddenly we need them and they are about £100 each."*
>
> *Mixed, non-selective, state school (Year 2 of the study)*

In year 3 of the study, prejudice against students in schools that were not able to access equipment to demonstrate all experiment was a concern for some staff.

> *"In a school where perhaps we are not as well-resourced as other schools, I think that if you … don't have access to all the apparatus …that the questions could be on apparatus that our students haven't seen before and I think that is really unfair on schools that don't have the ability [to provide the learning experience]…I mean I can show them a video but it is not the same as getting their hands on that bit of apparatus and I do think the exam board need to be really careful that the questions don't prejudice schools that aren't particularly well resourced, for whatever reason, and I think that is where it could be really unfair, both at GCSE and A level."*
>
> *Mixed, non-selective, state school (Year 3 of the study)*

Figure 45. (England – state schools): Stacked bar chart showing technicians' evaluation of biology or general science laboratory equipment in years 1 and 3 of the study (base n = 12383). Respondents were technicians.

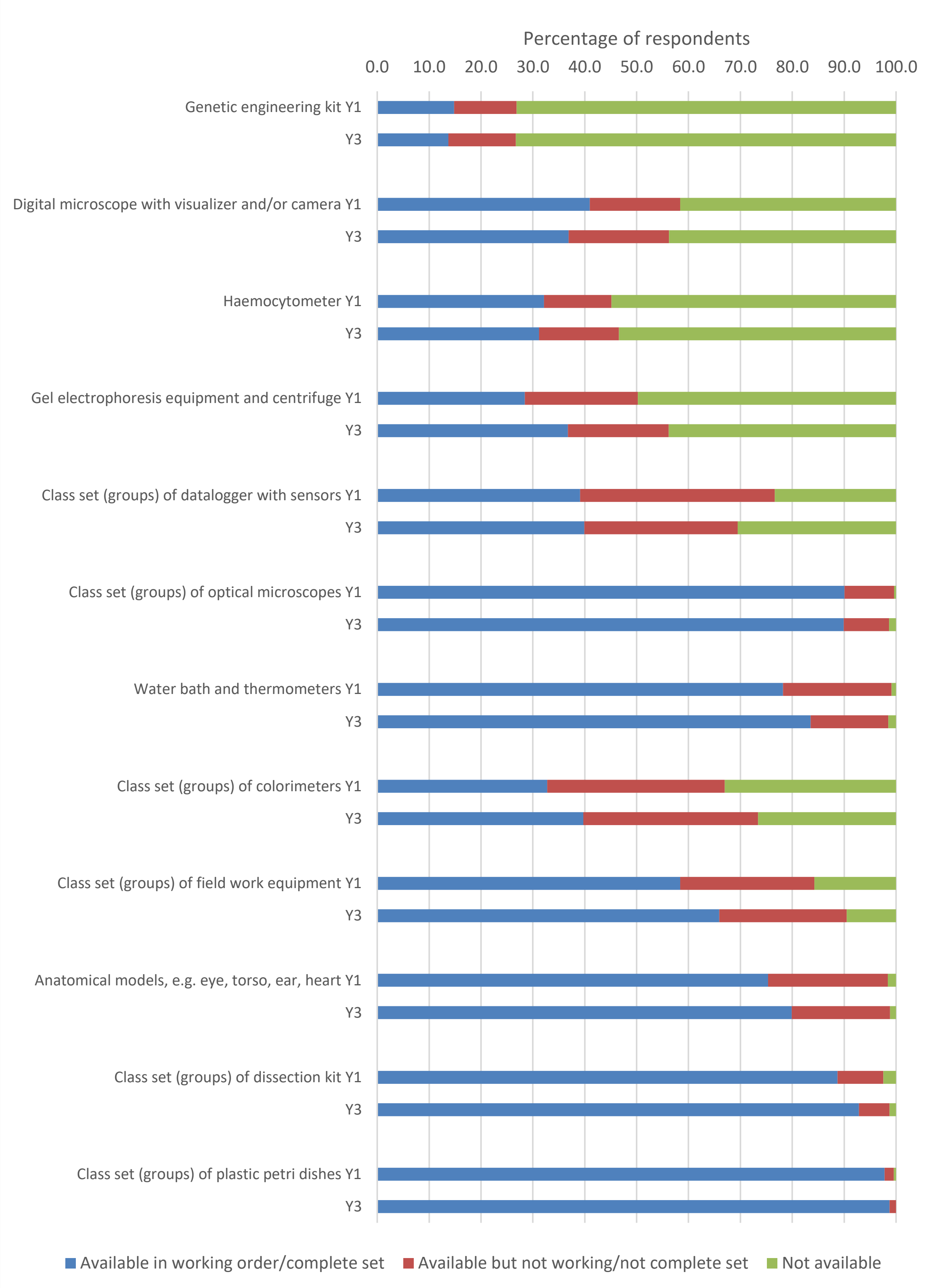


Figure 46. (England – independent schools): Stacked bar chart showing technicians' evaluation of biology or general science laboratory equipment in years 1 and 3 of the study (base n = 2449). Respondents were technicians.

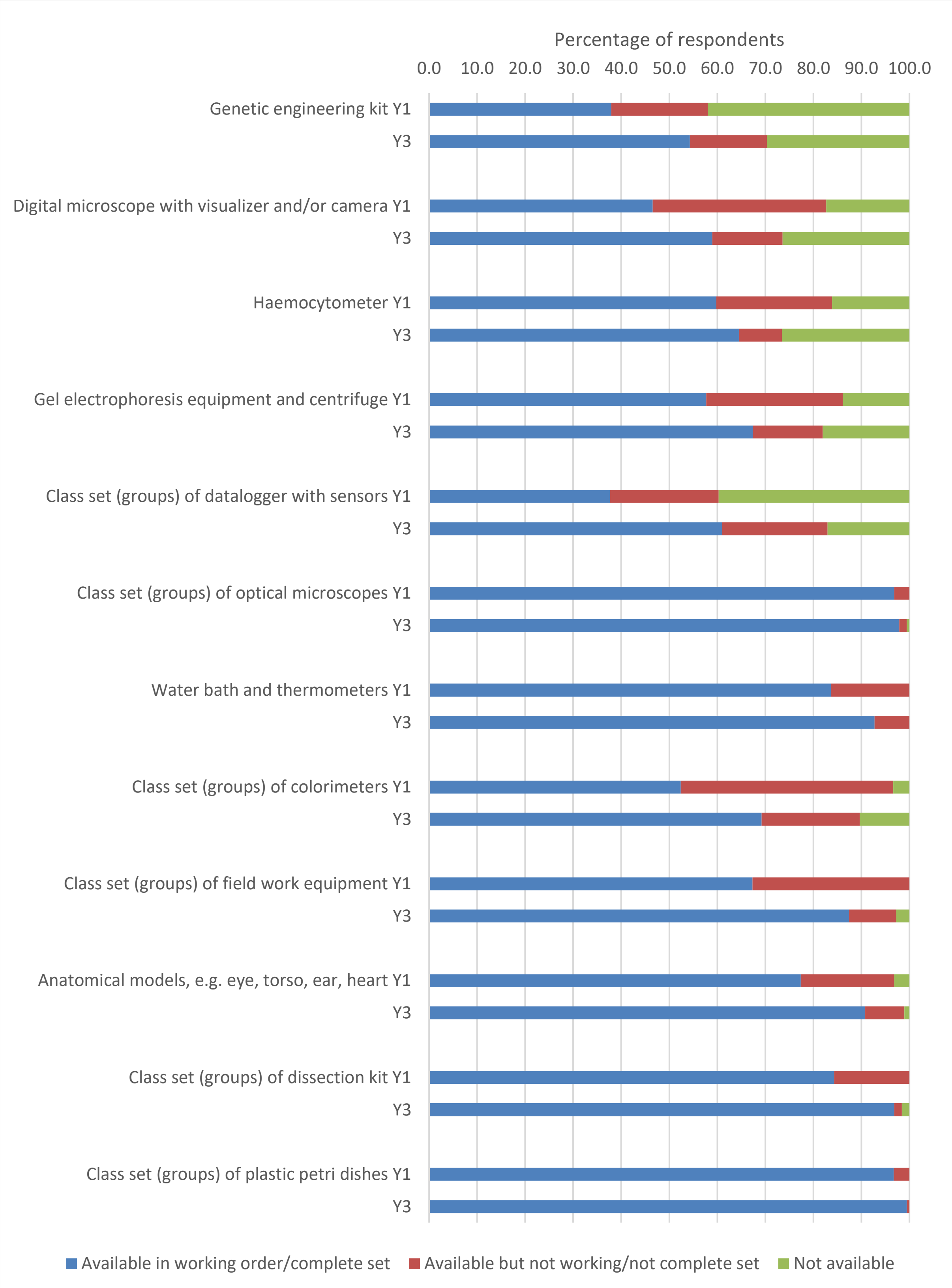


Figure 47. (Scotland- year 3 only): Stacked bar chart showing technicians' evaluation of biology or general science laboratory equipment in years 1 and 3 of the study (base n= 627). Respondents were technicians.

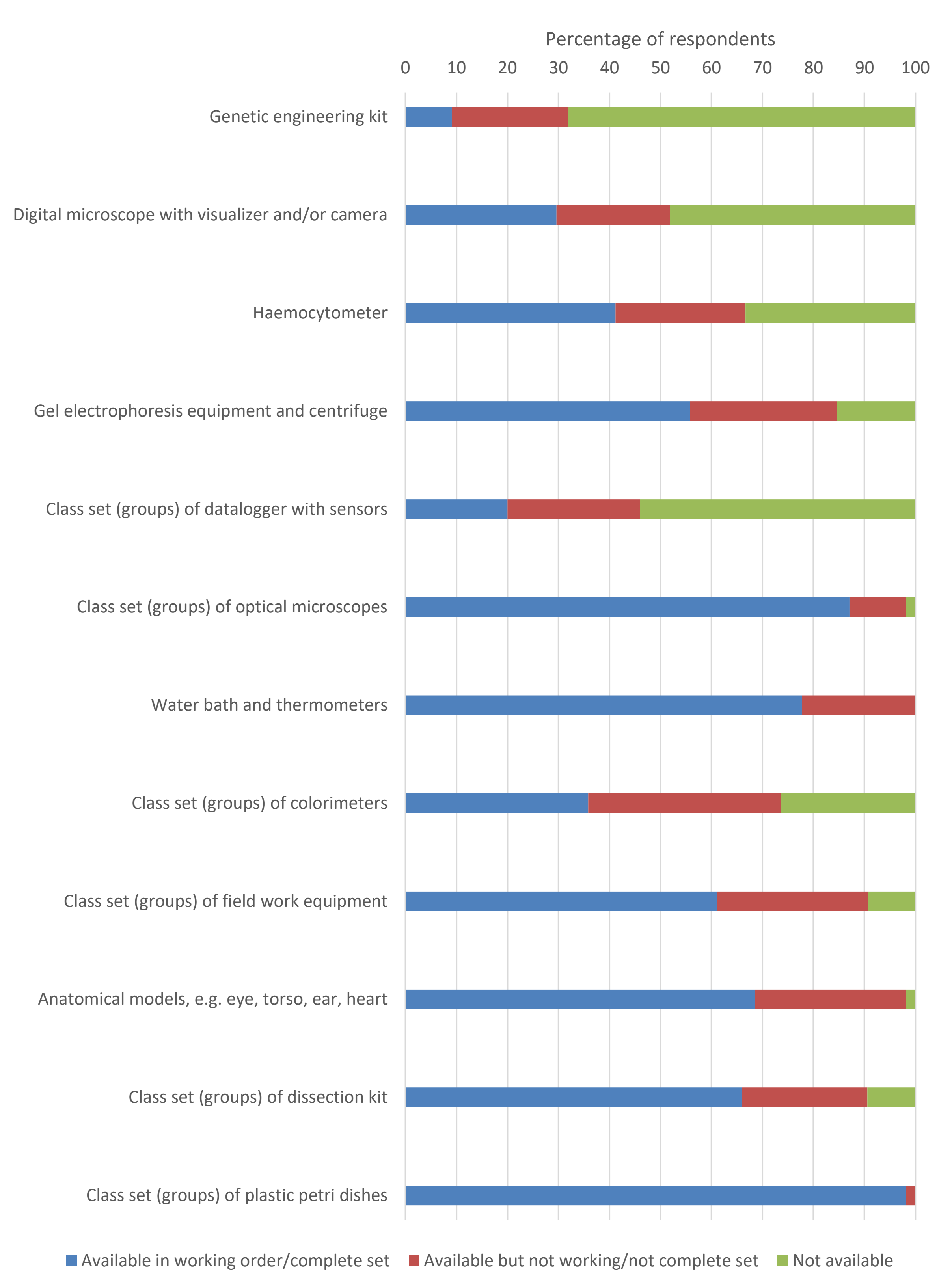


Figure 48. (England – state schools): Stacked bar chart showing technicians' evaluation of chemistry or general science laboratory equipment in years 1 and 3 of the study (base n = 12658). Respondents were technicians.

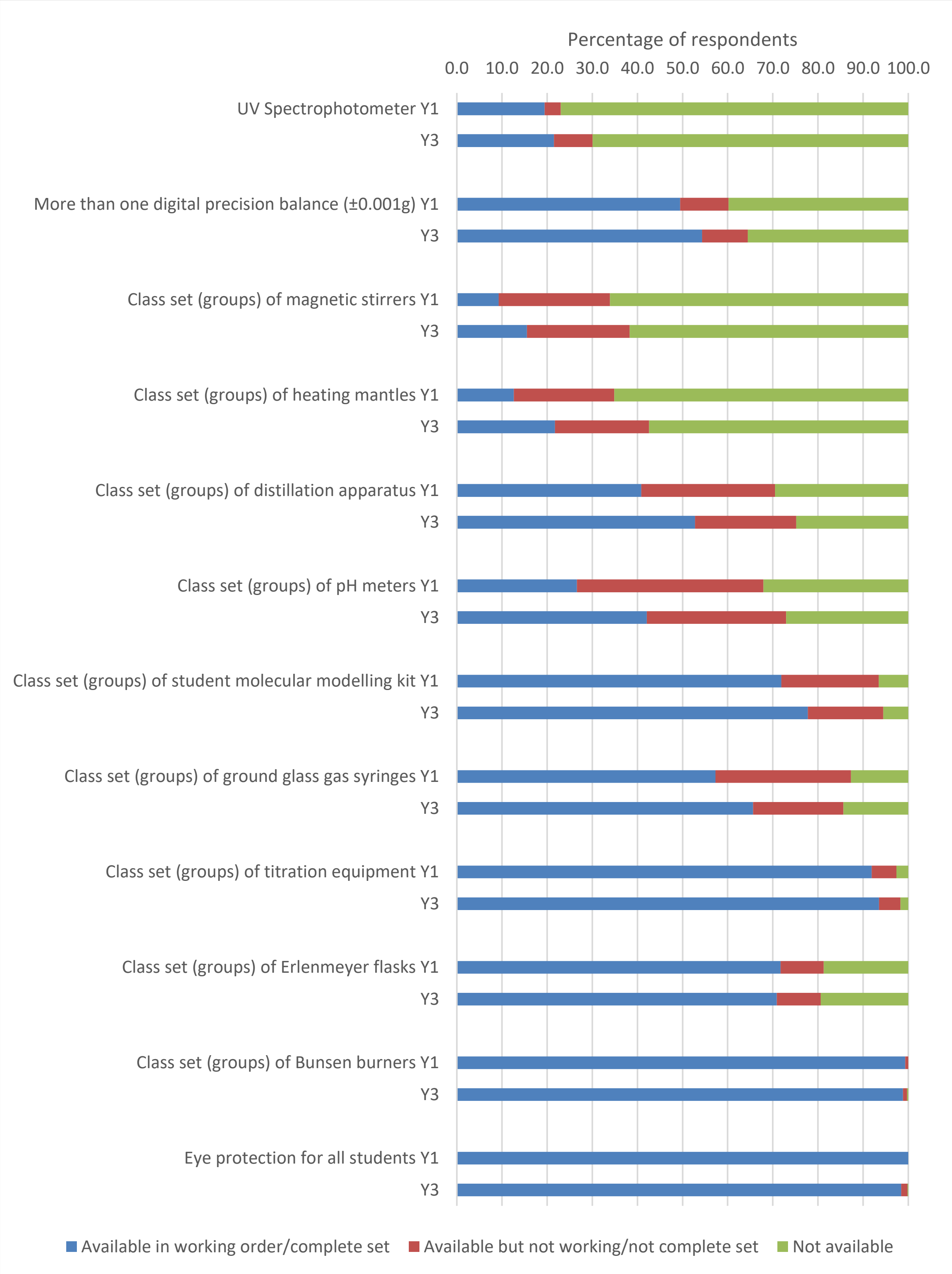


Figure 49. (England – independent schools): Stacked bar chart showing technicians' evaluation of chemistry or general science laboratory equipment in years 1 and 3 of the study (base n = 2420). Respondents were technicians.

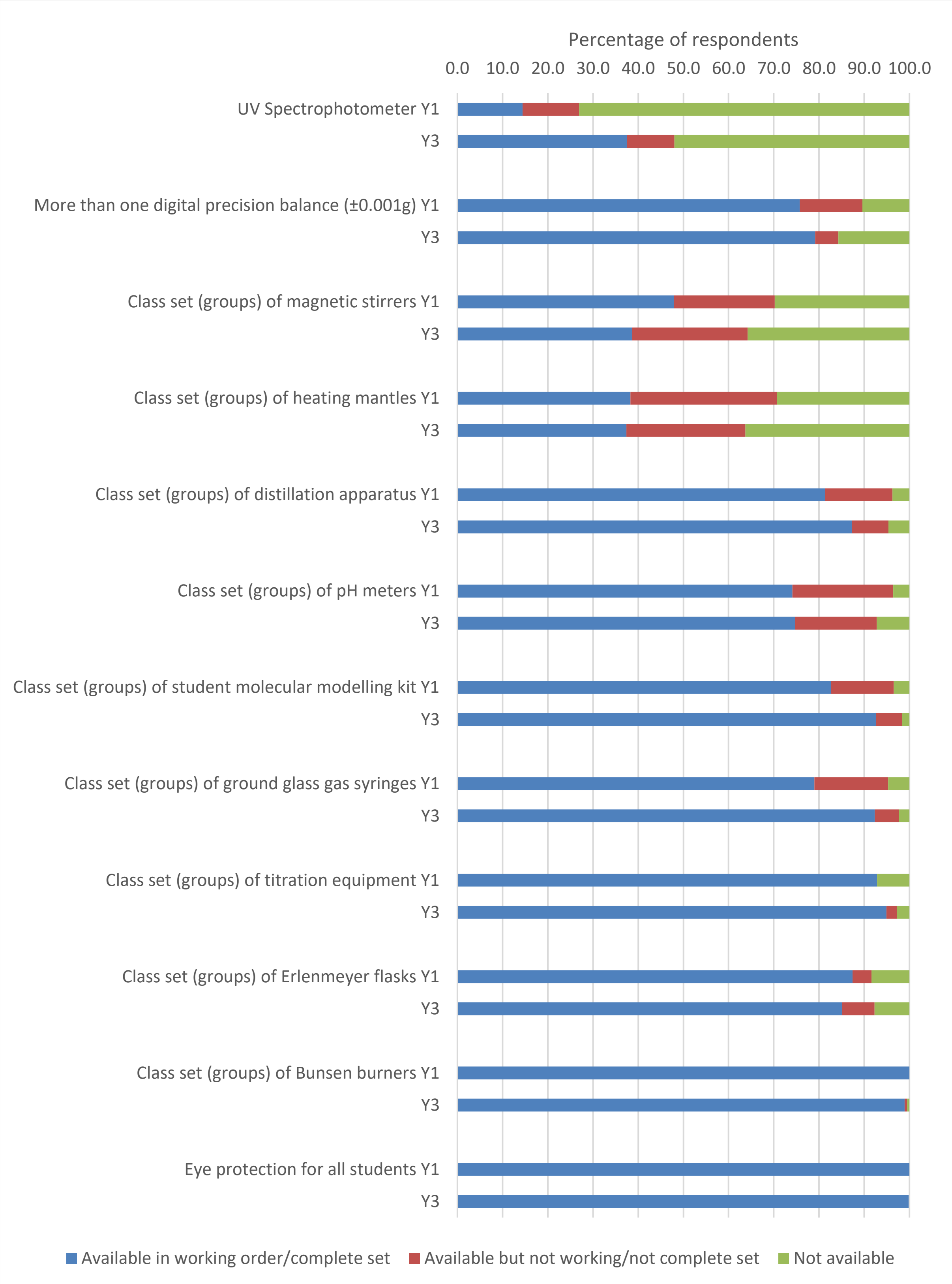


Figure 50. (Scotland – year 3 only): Stacked bar chart showing technicians' evaluation of chemistry or general science laboratory equipment (base n= 623). Respondents were technicians.

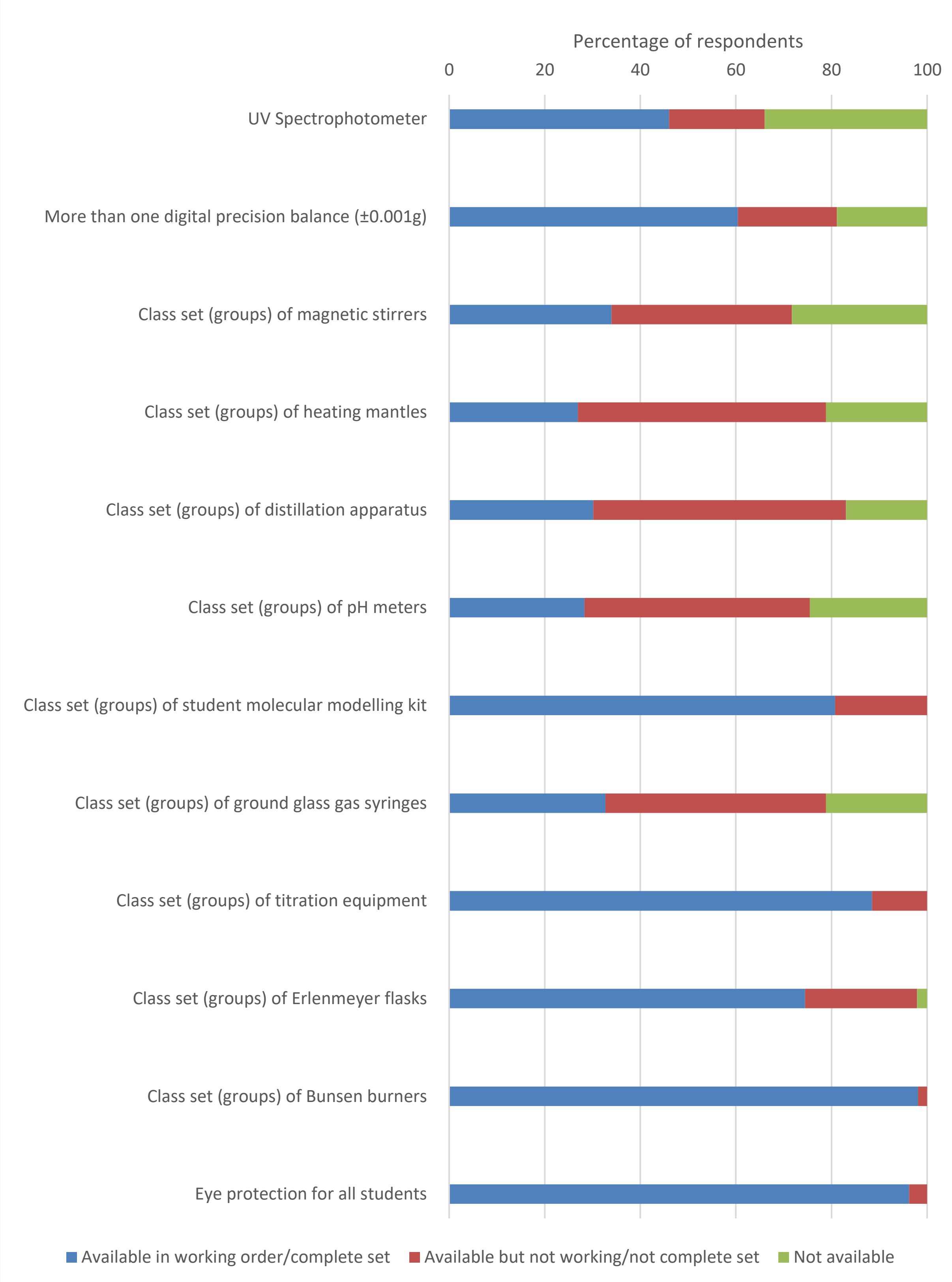


Figure 51. (England – state schools): Stacked bar chart showing technicians' evaluation of physics or general science laboratory equipment in years 1 and 3 of the study (base n = 12504). Respondents were technicians.

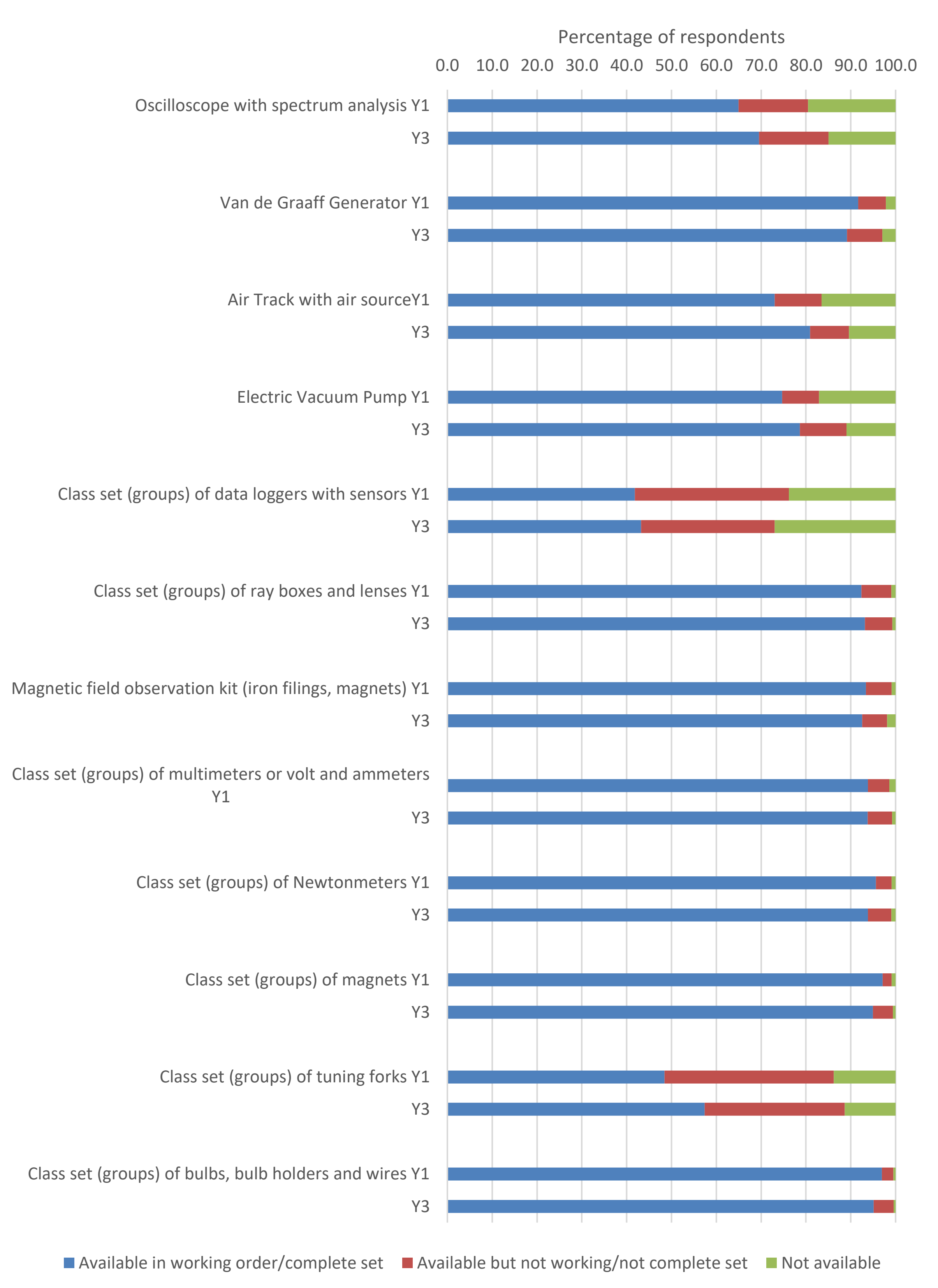


Figure 52. (England – independent schools): Stacked bar chart showing technicians' evaluation of physics or general science laboratory equipment in years 1 and 3 of the study (base n = 2656). Respondents were technicians.

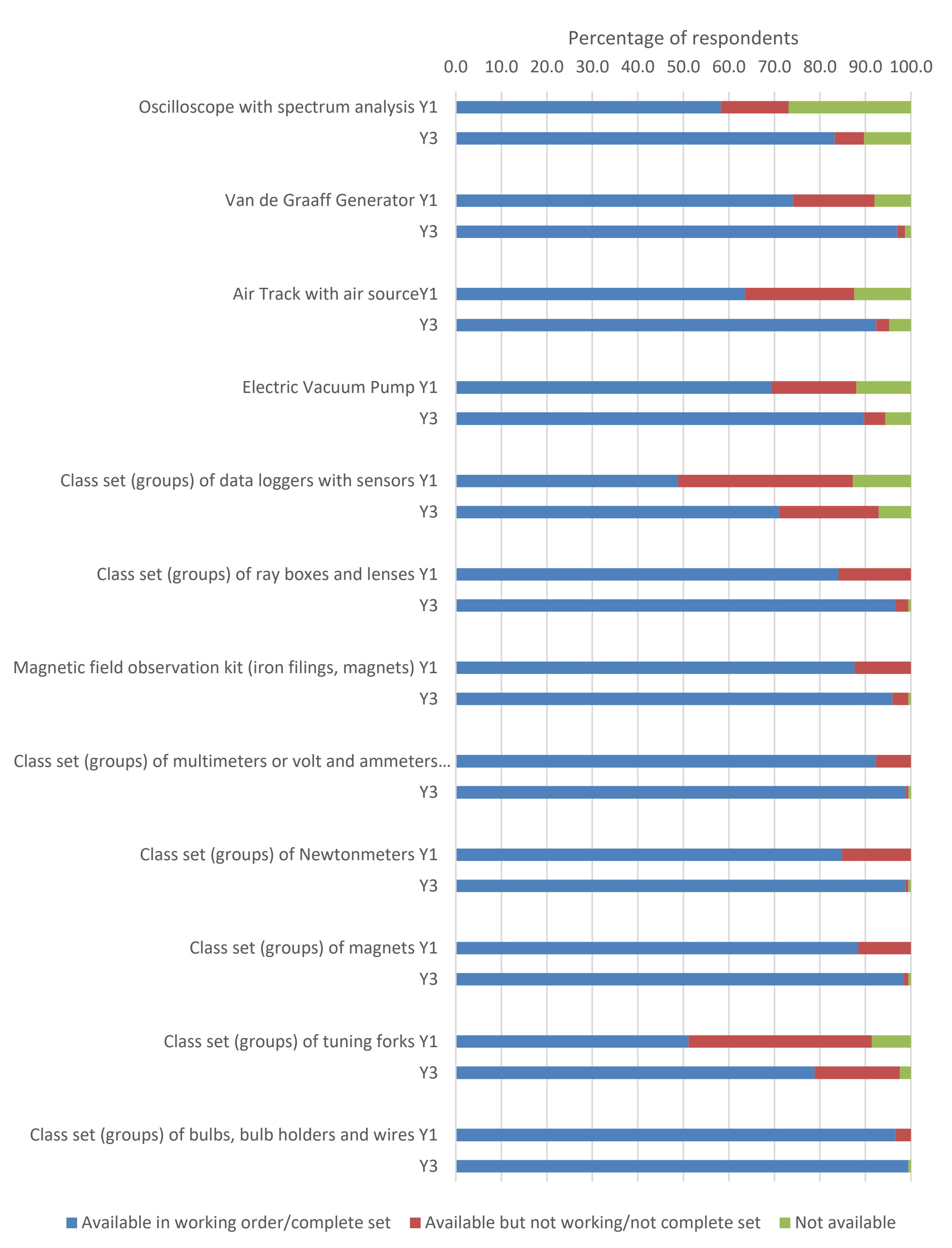
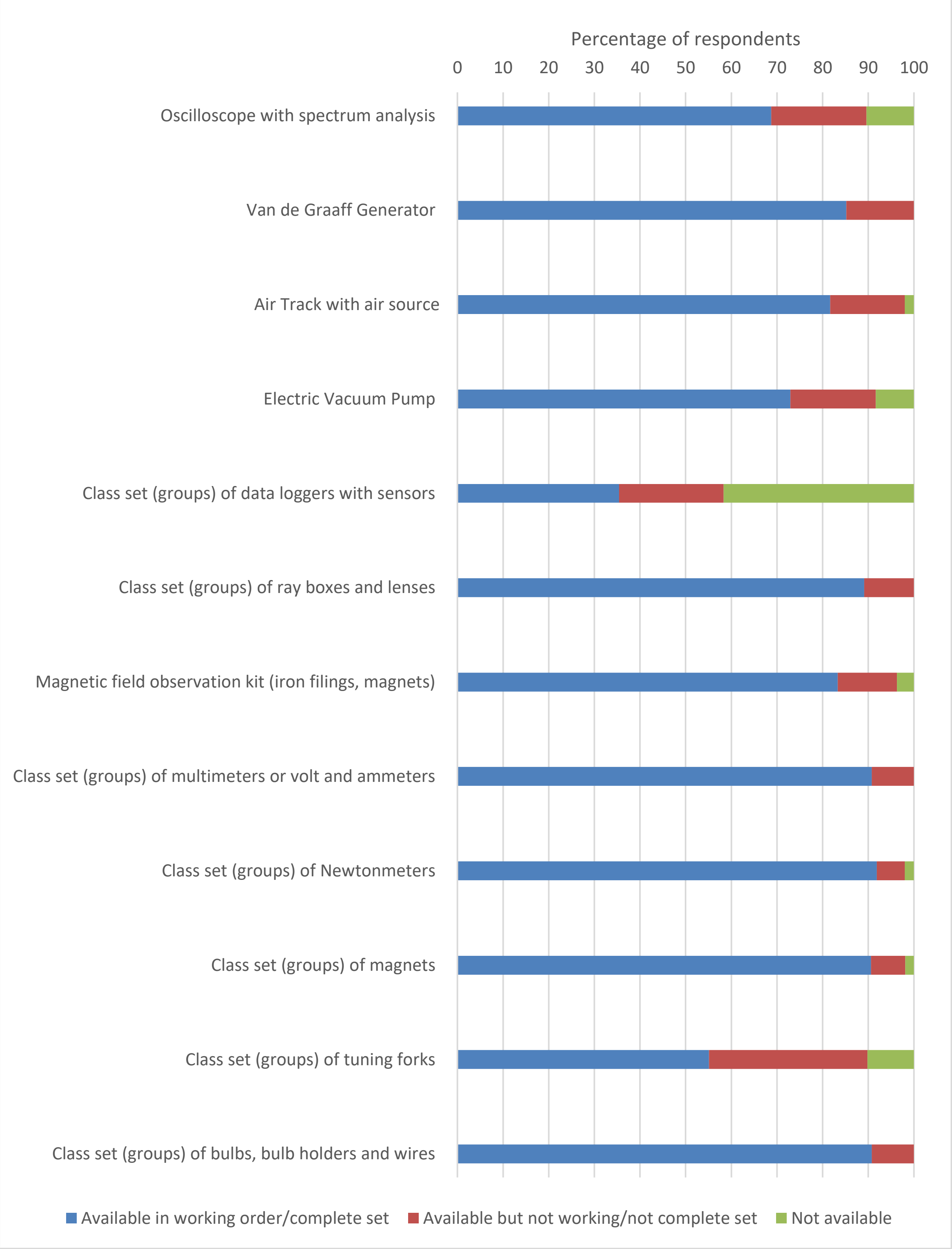


Figure 53. (Scotland – year 3 only): Stacked bar chart showing technicians' evaluation of physics or general science laboratory equipment (base n = 615). Respondents were technicians.



8.2.2.3 Satisfaction with factors affecting the delivery of high quality practical work

Heads of science were asked to report on their satisfaction on six factors in their department that may affect the delivery of high quality practical work (Figure 54 to Figure 56 and Table 54 in Appendix 3 to Table 56 in Appendix 3). The highest average level of satisfaction was reported in teachers having sufficient competency to carry out high quality practical work (being between satisfied to very satisfied). This was the only one of the six factor that heads of science from state schools in England reported being satisfied. However, in independent schools in England and state schools in Scotland other factors also had high level of satisfaction equal to teacher competency in some of the years of the study. A decrease in heads of sciences' average level of satisfaction with the sufficiency of laboratory facilities in their department was observed in independent schools in England between years 1 and 3 of the study.

Figure 54. (England – state) Bar chart showing heads of sciences' satisfaction with factors in their department for delivering high quality practical work. Respondents were heads of science (base n = 2656). Scale: 1 – Very dissatisfied, 2 – Dissatisfied, 3 – Neither satisfied nor dissatisfied, 4 – Satisfied 5 – Very satisfied. 95% confidence intervals are indicated on the graph.

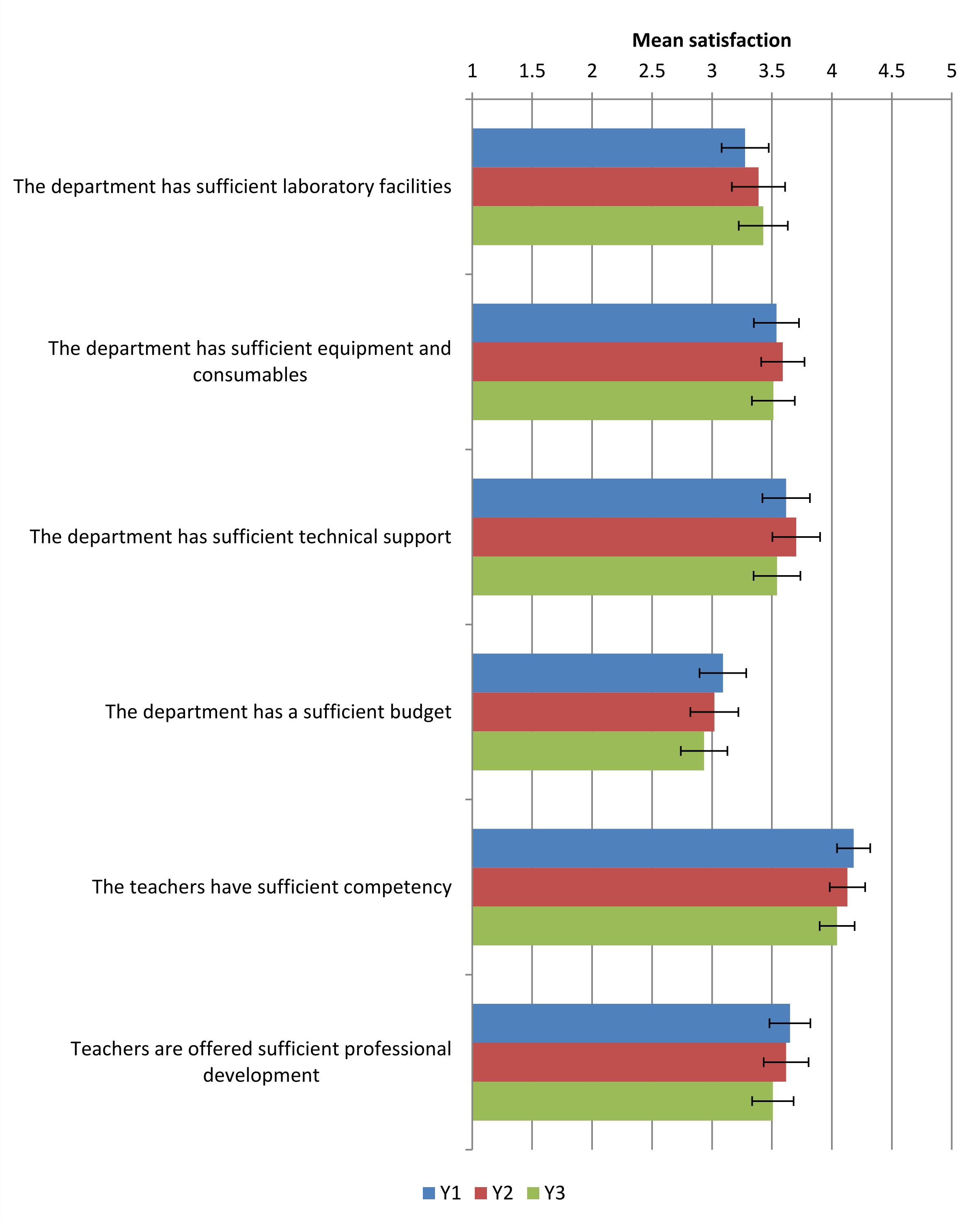


Figure 55. (England – independent) Bar chart showing heads of sciences' satisfaction with factors in their department for delivering high quality practical work. Scale: 1 – Very dissatisfied, 2 – Dissatisfied, 3 – Neither satisfied nor dissatisfied, 4 – Satisfied 5 – Very satisfied. Respondents were heads of science (base n = 1497). 95% confidence intervals are indicated on the graph.

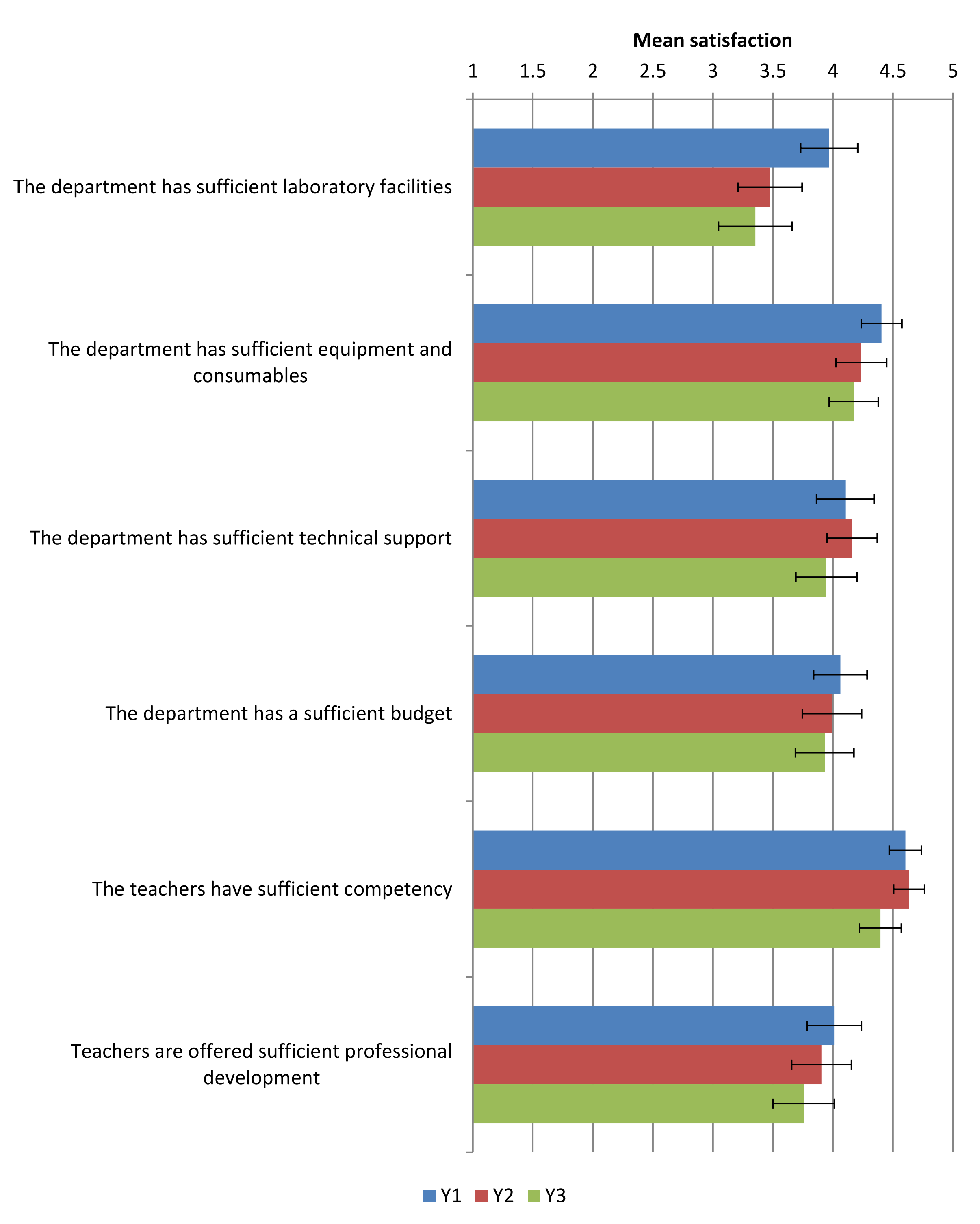
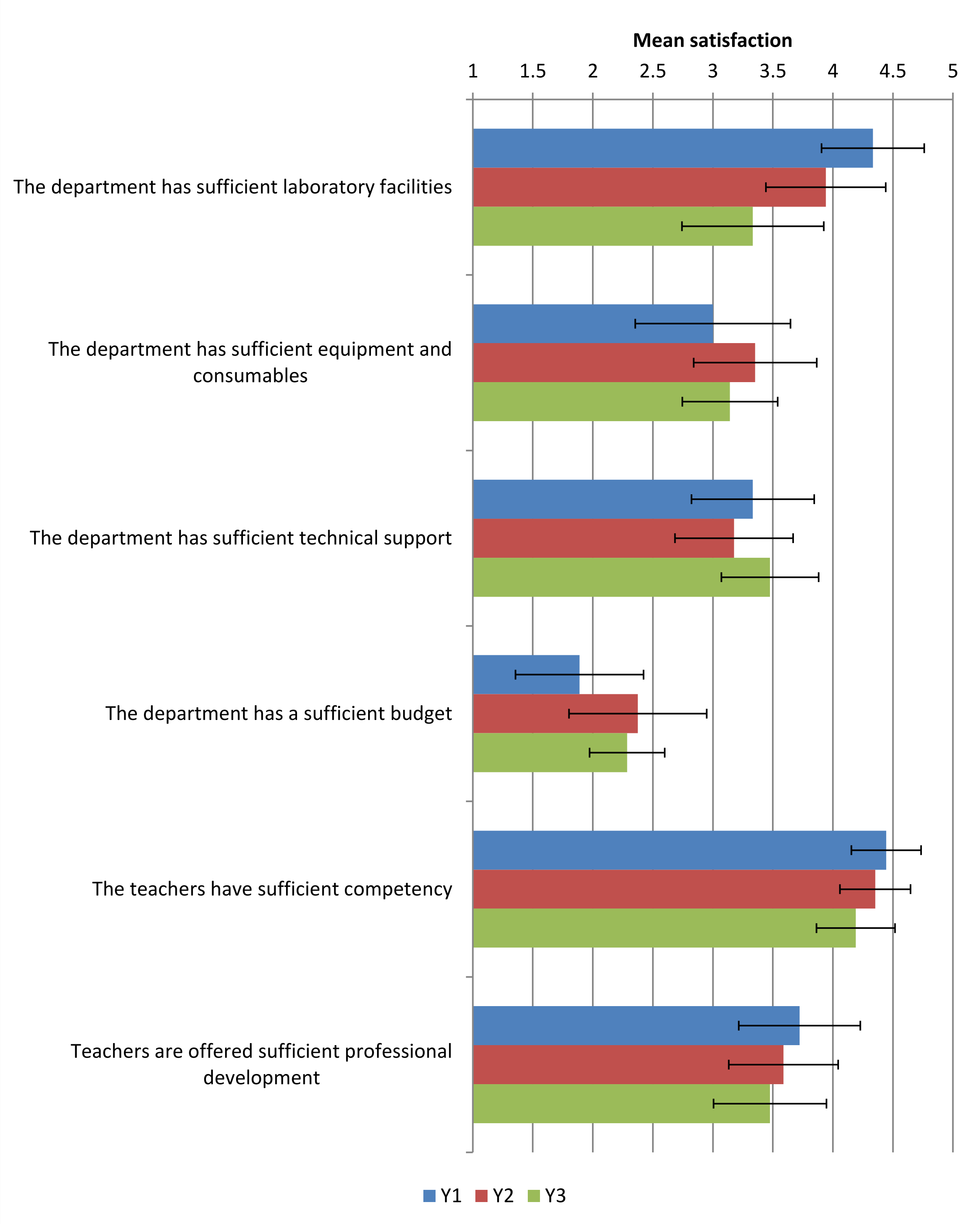


Figure 56. (Scotland) Bar chart showing heads of sciences' satisfaction with factors in their department for delivering high quality practical work. Scale: 1 – Very dissatisfied, 2 – Dissatisfied, 3 – Neither satisfied nor dissatisfied, 4 – Satisfied 5 – Very satisfied. Respondents were heads of science (base n = 335). 95% confidence intervals are indicated on the graph.

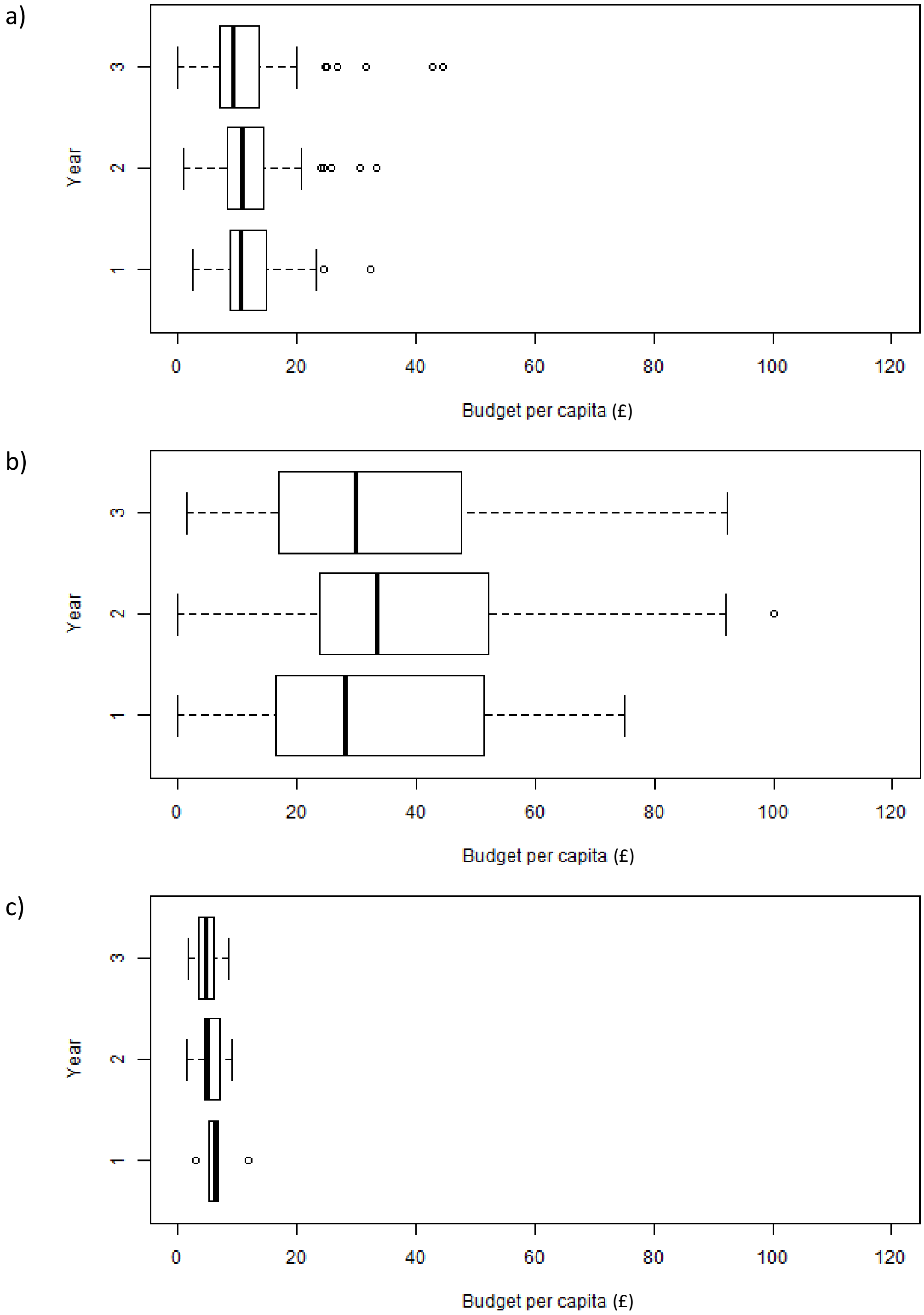


8.2.2.4 Budget

Science budget per capita

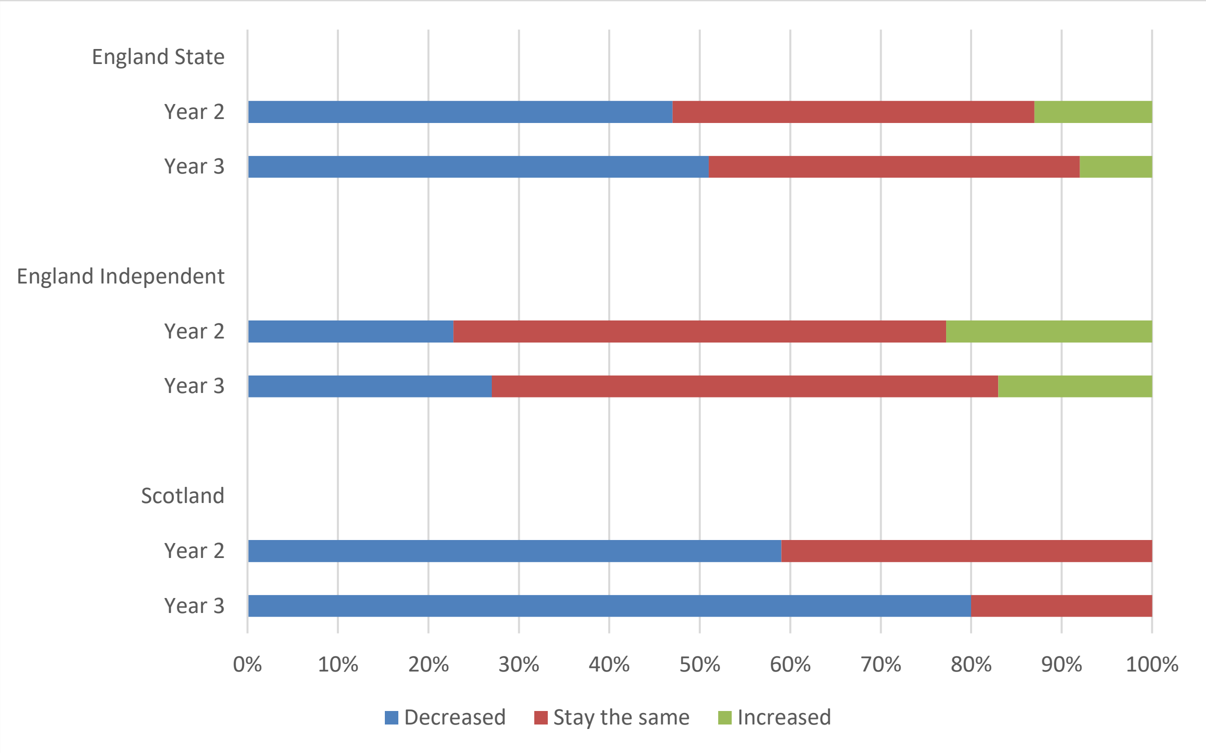
Respondents from state schools in England reported that their mean budget was £11 - £12 per pupil across the years of the study (Figure 57 and Table 57 in Appendix 3). Respondents from independent schools in England reported higher mean budgets than state schools of £33 - £37 per pupil across the three years of the study (2.75 – 3 times higher than state schools in England). In Scotland, the mean science budget per pupil was between £4 and £6 over the three years of the study. It is important to note that the way that budgets are allocated within schools was not asked as part of the survey and this may account for differences in observed budgets between school types and countries. Heads of science from independent schools in England had a higher average level of satisfaction than respondents from state schools in England as to whether their department had sufficient budget to carry out high quality practical work (Table 54 in Appendix 3 to Table 56 in Appendix 3).

Figure 57 (England and Scotland): Box plot of per capita science budget as reported by heads of science for a) English state schools, b) English independent schools, c) Scottish state schools in each of the three years of the study.



In addition to asking respondents to report on the amount they received as their departmental budget, in years 2 and 3, heads of science were also asked to report on whether their budget had increased, decreased or stayed the same since the previous year (Figure 58 and Table 58 in Appendix 3). In state schools in England, half of respondents reported that their budget had decreased since the previous year. In independent schools an equal percentage of respondents reported an increase as a decrease in year 2 of the study. No respondents from Scottish state schools reported an increase in either years 2 or 3 of the study.

Figure 58. (England and Scotland): Stacked bar chart showing heads of sciences' reporting as to how their departmental budget had changed since the previous year (years 2 and 3 of the study).



Impact of budget

The findings from the question to heads of science about their satisfaction as to whether their department had sufficient budget to carry out high quality practical work showed that respondents from independent schools in England had a higher average level of satisfaction than respondents from state schools in England (Table 54 in Appendix 3 and Table 55 in Appendix 3). This was supported by comments from participants in the focus groups and telephone interviews. However, discussions with participants also showed that not all independent schools are well resourced and able to purchase any equipment that they require.

Example: Budget

Focus group and telephone interview participants provided additional detail about the impact of budgets on their ability to purchase equipment.

> *"I think our issue now is that the school gets very good results and schools who get very good results aren't going to be given more money to improve their infrastructure if they are getting very good results."*
>
> *Mixed, non-selective, state school (Year 1 of the study)*
>
> *"The budget is … a particular issue for physics … [as] it tends to have [a] few bits of expensive equipment rather than a large number of inexpensive [items]. One of the issues for me has been that much of the stuff I find in cupboards and found the receipt for … is [from] … 1959, 1961 … but to replace it would be a third of my capitation … we bid for things and we keep on being turned down for some things … You need to spend more money to stand still because, … we don't want rubbish data loggers when [the students'] phones are all better than them."*
>
> *Girls, selective, independent school (Year 2 of the study)*
>
> *"[There is] a capital item budget which is really good so you can name large items and put them on a wish list and you might be able to buy one [in] one year or [in] a couple of years down the line... So you can have [a] long term strategy for things you might want to do and we work quite well across departments and again with particular items of expense; data loggers have been a good example where you can share that expenditure."*
>
> *Mixed, selective, independent school (Year 2 of the study)*

8.3 How does practical science contribute to preparing students for their next steps in science education?

An aim for this study was to measure how practical science in schools prepares students for their next phase in science education. Perceptions of preparedness in various elements of practical work were investigated with heads of science, science teachers and staff involved with teaching of first year undergraduate laboratories. The HE staff and student survey samples are described in sections 7.2.3 and 7.2.5.

Key findings:

Preparation for next phase of education within school

Heads of science and science teachers were asked to rate on a five point scale how well prepared they considered their students to be at the start of their particular phase of education. Of the four aspects of practical work presented to rate, heads of science and science teachers in all age ranges in both England and Scotland considered their students to be best prepared at the start of each phase of their education at 'following prepared instructions'.

HE staff perception of students' preparation for studying laboratory courses at university

HE staff were presented with a list of 18 skills and asked to rate the importance of students arriving at university with those skills. In biological sciences and chemistry, HE staff considered the ability to follow laboratory instructions, follow health and safety instruction and to understand laboratory and/or fieldwork instructions to be the most important skills for students to have on arrival at university. In biological sciences and chemistry, competence in scientific methods and practices, specifically: note-taking became quite important by the third year of the study, whilst in biological sciences and physics, understanding the theory behind the scientific method and the ability to solve problems independently in a practical context became quite important skills to students to have on arrival at university. Discussion in the telephone interviews supported these findings, with HE staff stating that they did not consider it essential for students to arrive at university with specific technical scientific skills e.g. how to use an oscilloscope. Instead, they wanted students who are able to operate safely within the laboratory environment and to follow and understand the instructions presented to them. Over the three years of the study, HE staff were considering a wider range of basic skills to be important for students to arrive with at university.

In all three subjects, across all three years, HE staff considered there to be no skills in which students arrived at university somewhat to well prepared. In contrast, first year undergraduate students considered themselves to be somewhat prepared in many of the same skills. However, physics students considered themselves less well prepared than biological sciences and chemistry students.

Although HE staff considered students not to be well prepared on arrival at university, they did report significant improvements in their perceived level of preparedness for first year undergraduates in several skills over each of the three years of the study.

HE staff generally considered students to be best prepared in the skills which they rated as being most important for them to have on arrival at university, with a strong positive correlation observed between importance and preparedness in year 1 and 2 of the study in chemistry and in year 1 of the study in physics. A moderate positive correlation between importance and preparedness was observed for all other years in biological sciences, chemistry and physics.

First year undergraduates' perception of preparation for arrival at university

In general, HE students did not report that their post- 16 education had prepared them very well for laboratory courses and/or fieldwork in their first year at university. However, biological sciences and chemistry students were more positive than physics students.

A small proportion of first year undergraduate students reported experiencing laboratory or fieldwork activities in which they felt unable to do well because they didn't have the right practical skills in their first term at university.

Reasons and importance for carrying out practical work

From open discussion in the telephone interviews, HE staff stated four common themes for the reasons why they thought practical work was important within science degrees. These were: accreditation requirements, employability skills, reinforcing knowledge, and understanding the world through experimentation and observation.

HE staff stated in open discussion that the reasons they undertook practical work in their first year undergraduate courses were for improving: skills, knowledge and thinking, communication and health and safety.

Changes during the period of reforms to GCSE and A level courses

HE staff commented that knowing the details of the reforms to the GCSE and A level science curricula was difficult outside the school system.

HE staff were asked to select from a list, any changes that they had made within their curriculum content and teaching to accommodate students' practical work skills and knowledge on transition from post – 16 education to university. In all three years of the study in all subjects, 'making changes to laboratory based teaching' was the adjustment that the highest (or equal highest) percentage of HE staff indicated having made.

Over the course of the study, an increasing percentage of HE staff reported a decline in the 'level of knowledge' of biological sciences students since the previous year (or in the previous five years in year 1 of the study). However, it should be noted that the sample size is small. In chemistry over the three years of the study, an increased percentage of HE staff reported an increase in 'laboratory skills' since the previous year, with fewer staff reporting a decline in 'laboratory skills', 'ability to plan experiements' and 'ability to work independently in the laboratory'. Physics had a reduction in the percentage of HE staff reporting a decline in 'laboratory skills' since the previous year, over the course of the study. These findings should be interpreted with caution due to the small sample size.

8.3.1 How well prepared do heads of science and science teachers in schools consider their students to be in each stage of their education?

Heads of science and science teachers were asked to rate on a five point scale how well prepared they considered their students to be at the start of their particular phase of education at: writing scientific reports, using scientific equipment, following prepared instructions and conducting work in a laboratory. At the start of the 11 – 14, and 14 – 16 age ranges in both state and independent schools in England, respondents considered their students to be best prepared at following prepared instructions (Figure 59 to Figure 62 and Table 59 in Appendix 3 to Table 62 in Appendix 3). In both age ranges, using science equipment was the activity which respondents considered their students to be next best prepared. In the post – 16 age range, staff considered students to be similarly prepared at following instructions and using scientific equipment (Figure 63 to Figure 64 and Table 63 in Appendix 3 and Table 64 in Appendix 3). In Scotland, the difference between skills was less clear cut. However, staff in the 11 - 14 age range considered their students to be less well prepared than staff in the 14 – 16 and post – 16 age ranges.

Figure 59. 11 – 14 age range (England – state schools): Stacked bar chart showing how well prepared staff considered their students to be for specific aspects of practical activities/experiments at the start of the 11 – 14 phase of their education for each of the three survey years and by subject. Respondents were heads of science and science teachers.

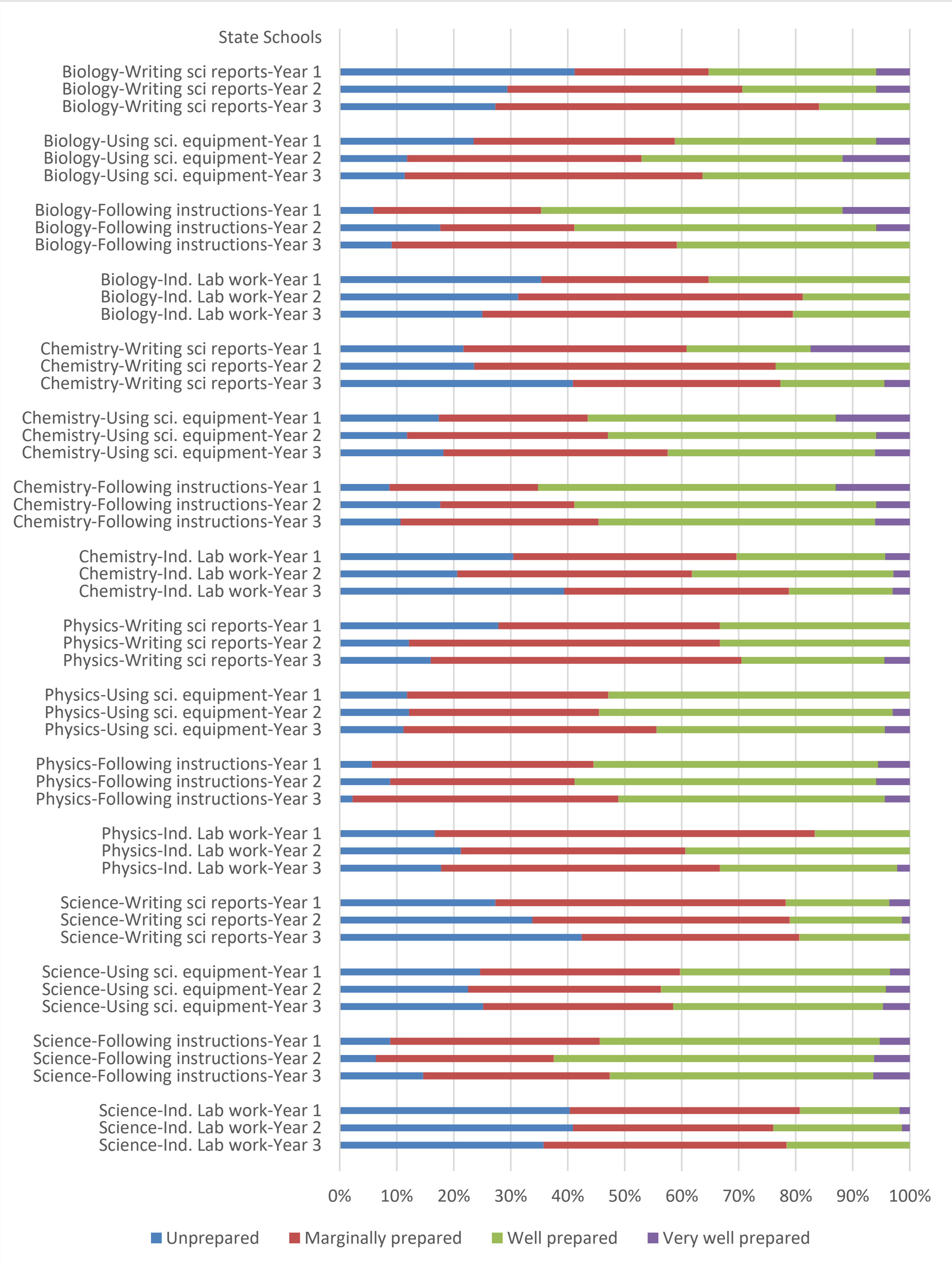


Figure 60. 11 – 14 age range (England – independent schools): Stacked bar chart showing how well prepared staff considered their students to be for specific aspects of practical activities/experiments at the start of the 11 – 14 phase of their education for each of the three survey years and by subject. Respondents were heads of science and science teachers.

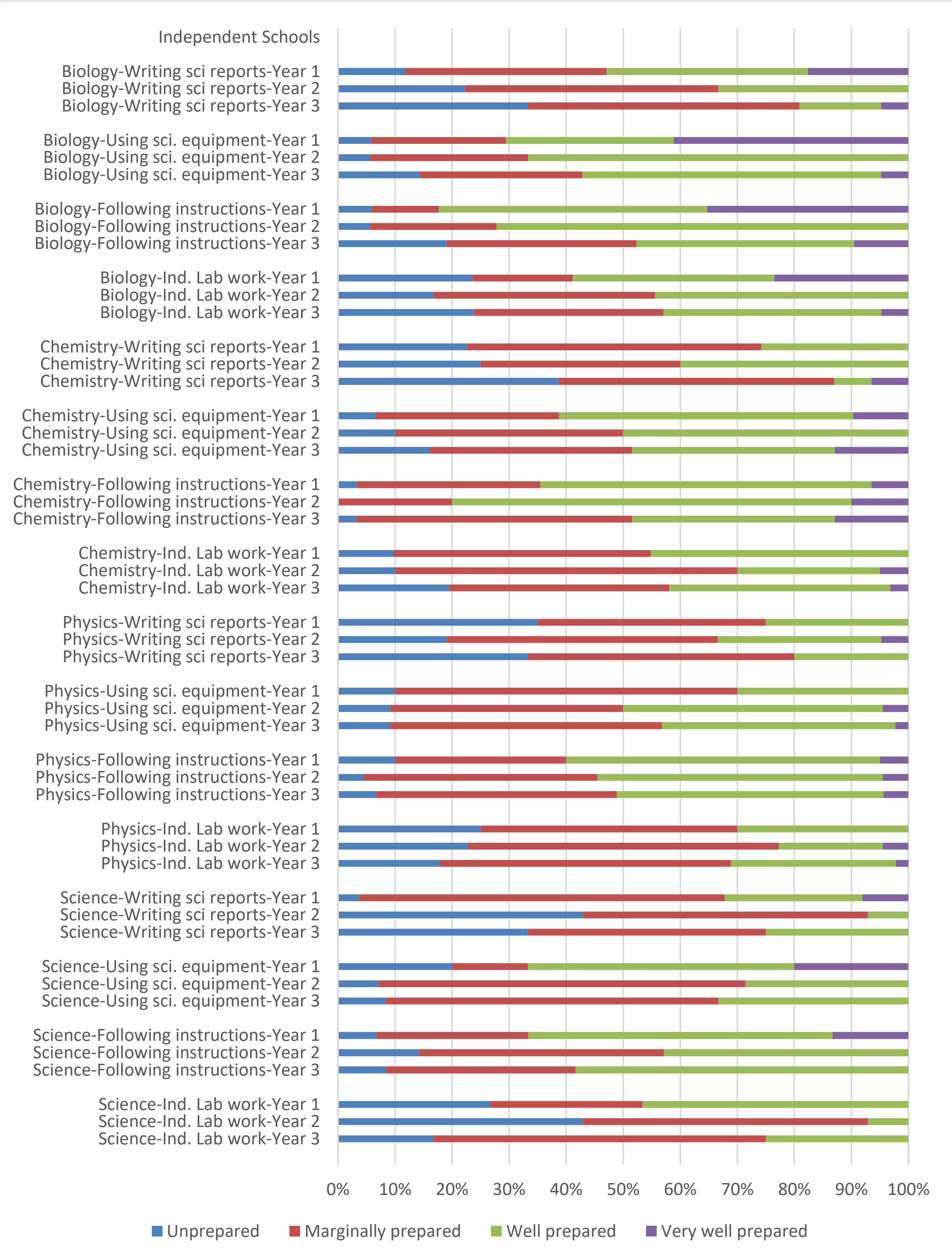


Figure 61. 14 – 16 age range (England – state schools): Stacked bar chart showing how well prepared staff considered their students to be for specific aspects of practical activities/experiments at the start of the 14 – 16 phase of their education for each of the three survey years and by subject. Respondents were heads of science and science teachers.

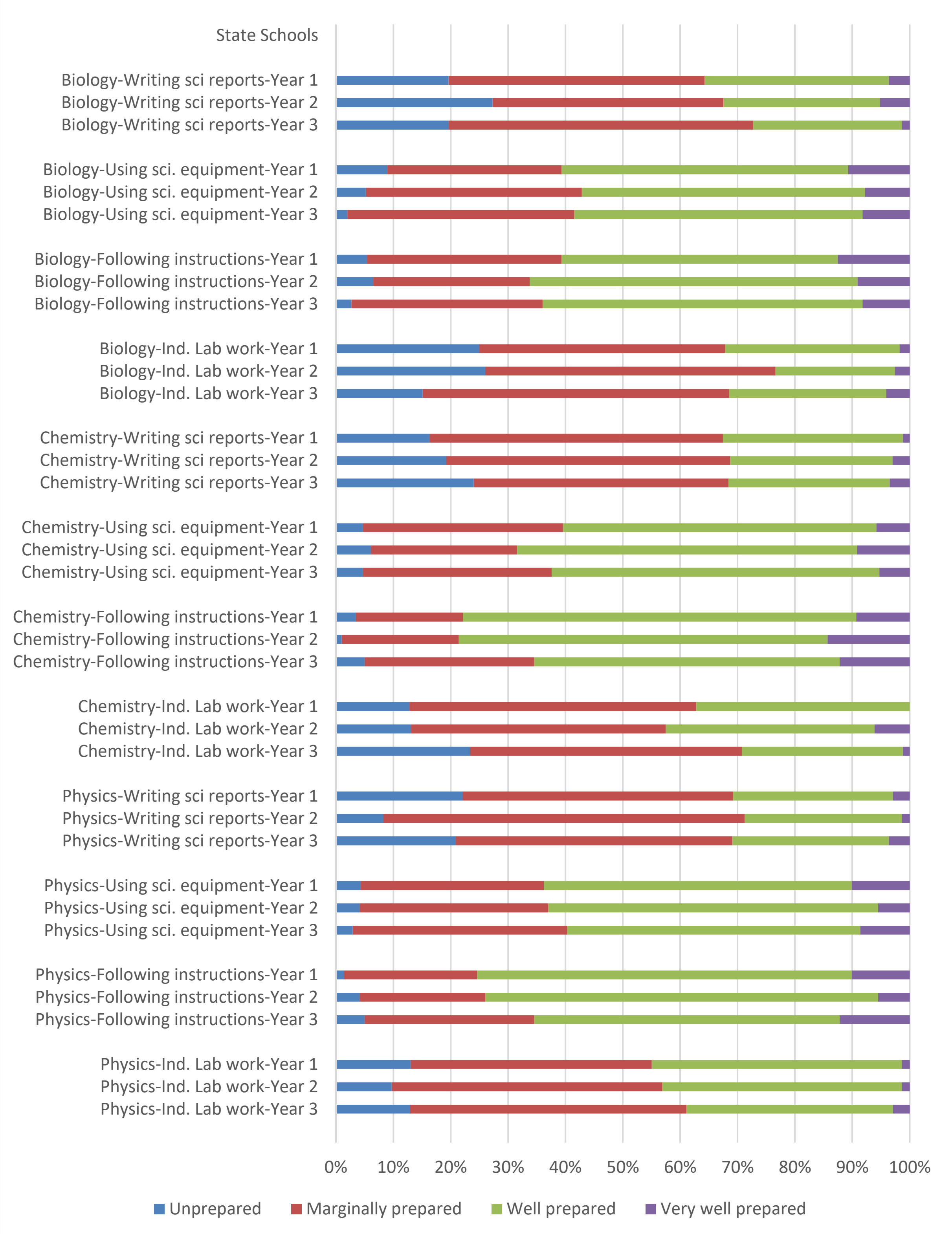


Figure 62. 14 – 16 age range (England – independent schools): Stacked bar chart showing how well prepared staff considered their students to be for specific aspects of practical activities/experiments at the start of the 14 – 16 phase of their education for each of the three survey years and by subject. Respondents were heads of science and science teachers.

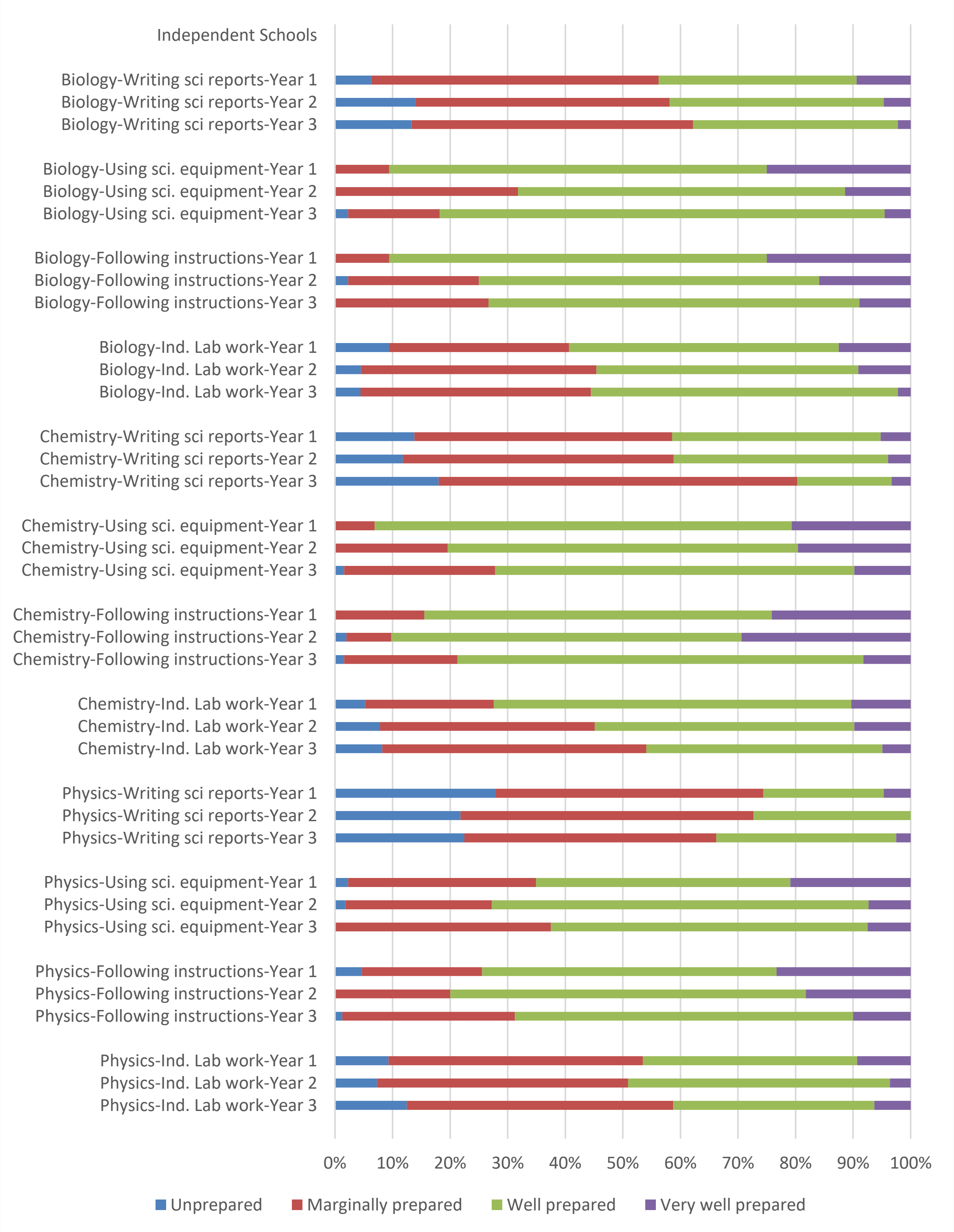


Figure 63. Post – 16 age range (England – state schools): Stacked bar chart showing how well prepared staff considered their students to be for specific aspects of practical activities/experiments at the start of the Post – 16 phase of their education for each of the three survey years and by subject. Respondents were heads of science and science teachers.

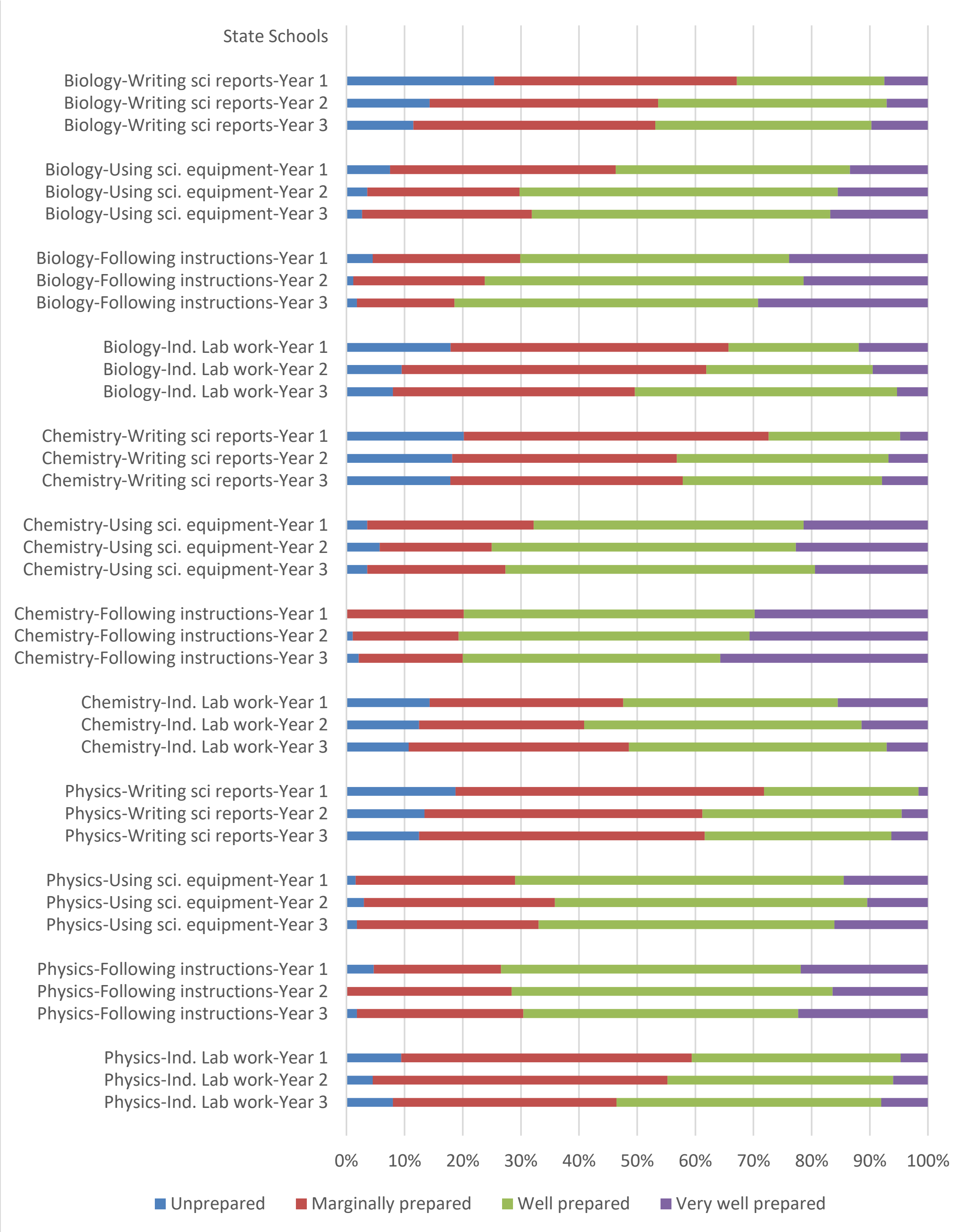


Figure 64. Post – 16 age range (England – independent schools): Stacked bar chart showing how well prepared staff considered their students to be for specific aspects of practical activities/experiments at the start of the Post – 16 phase of their education for each of the three survey years and by subject. Respondents were heads of science and science teachers.

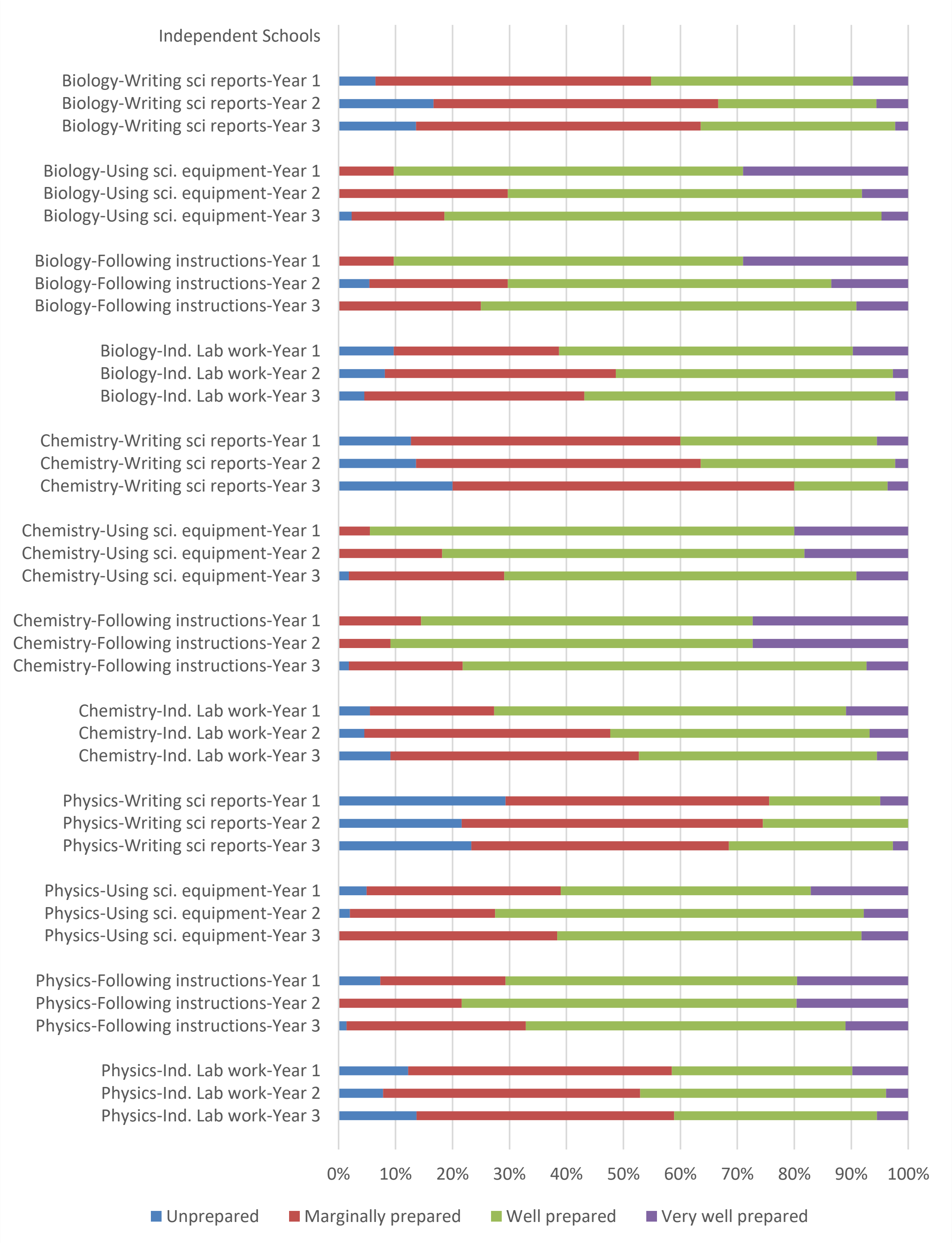
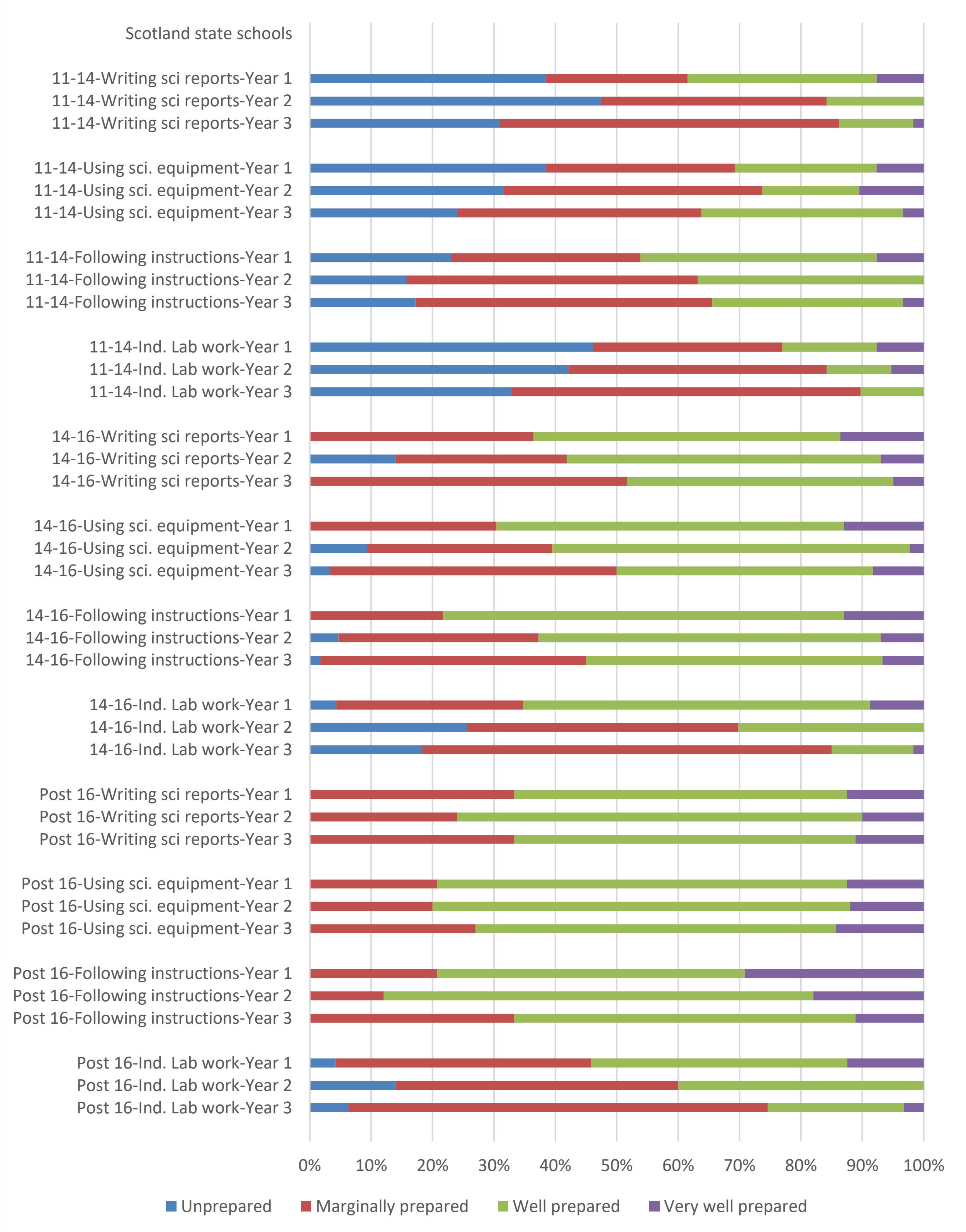


Figure 65. All age range (Scotland): Stacked bar chart showing how well prepared staff considered their students to be for specific aspects of practical activities/experiments at the start of each phase of their education for each of the three survey years. Respondents were heads of science and science teachers.



8.3.2 What skills and knowledge do university staff and students expect and find sufficient in first year undergraduate students?

HE staff were asked about the skills and knowledge they expect first year undergraduate students to have on arrival at university and whether students had the levels of skills and knowledge expected. First year undergraduate students who were studying a science degree containing a practical laboratory course were asked how well prepared they were for university practical work in using a range of skills. Despite a range of methods to increase participation (section 8.2, Appendix 1), the number of students responding was low in each of the three years of the study, and so student data is used narratively rather than quantitatively.

Biological sciences

HE staff involved with the teaching of biological sciences laboratory courses considered the ability to follow laboratory instructions; follow health and safety instructions; and to understand laboratory and/or fieldwork instructions to be the most important skills for students to have on arrival at university in all three years (Figure 66). However, in year 3, several other skills had also become of equally high importance. In all three years, HE staff on average did not rate their students to be 'somewhat prepared' or 'very well prepared' in any skills. By comparison, feedback from HE students was that in general they considered themselves to be somewhat prepared in the majority of skills.

Although HE staff did not consider students to be 'somewhat prepared' on arrival at university, they did consider students' preparedness to be improving year-on-year in nine of the 18 skills listed (Table 28). A moderate positive correlation was observed in each year between the perceived importance of skills by HE staff and their estimation of students' preparedness in those skills (Table 66 in Appendix 3).

Figure 66. Biological sciences: Perceived importance of skills and preparedness of students on arrival at university. Respondents were HE staff involved with the teaching of first year undergraduate laboratory courses. Scale - Preparedness: year 1: 1 - Generally poor, 3 - Some capability, 5 - Well prepared. Years 2 and 3: 1 – Not at all prepared, 2 – Somewhat unprepared, 3 – Neither prepared nor unprepared, 4 -Somewhat Prepared, 5 - Very well prepared. Importance: 1 Very unimportant, 2 Quite unimportant, 3 Neither, 4 Quite important, 5 Very important. (n =60). 95% confidence intervals are indicated on the graph.

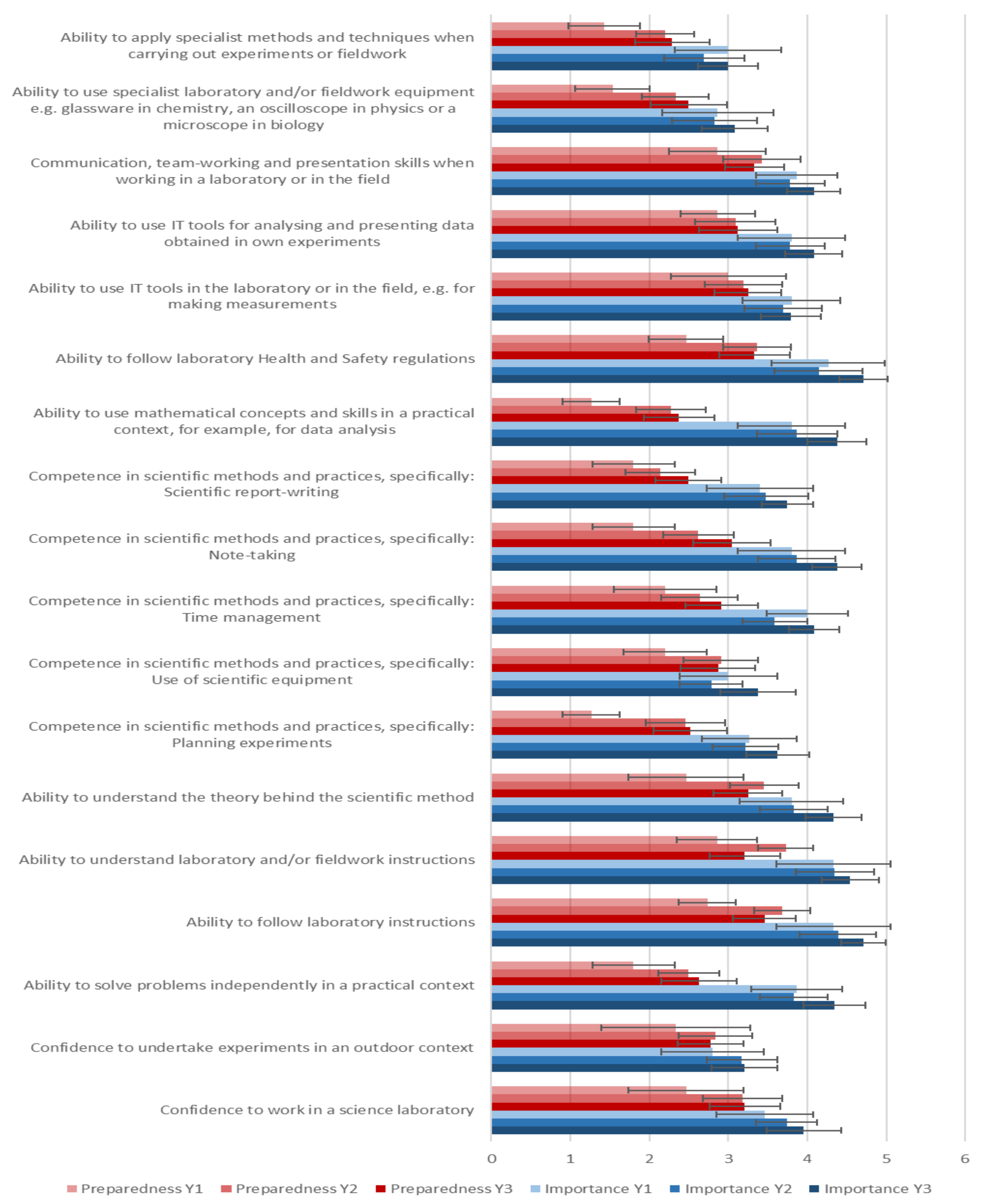


Table 28. Biological sciences: Rate of change per year of the perceived importance of skills and preparedness of students. Respondents were HE staff from all three years of the study involved with the teaching of first year undergraduate laboratory courses. A statistically significant rate of change per year in the level of importance or preparedness over the three years of the study is highlighted in bold with the level of significance stated below the table. Note: the dependent variable in each case is the staff rating of the importance or preparedness for each skill. The rate of change per year is an estimate of the change per year in the Likert scale response over the 3 years of the study.

	Importance		Preparedness	
First year undergraduate skill	**n**	**Rate of change per year (five point Likert scale)**	**n**	**Rate of change per year (five point Likert scale)**
Confidence to work in a science laboratory	62	0.243	61	0.341
Confidence to undertake experiments in an outdoor context	62	0.189	45	0.183
Ability to solve problems independently in a practical context	61	0.264	61	**0.388***
Ability to follow laboratory instructions	62	0.199	61	**0.312***
Ability to understand laboratory and/or field work instructions	62	0.112	60	0.106
Ability to understand the theory behind the scientific method	62	0.288	61	0.340
Competence in scientific methods and practices, specifically: Planning experiments	62	0.199	60	**0.583***
Competence in scientific methods and practices, specifically: Use of scientific equipment	62	0.223	60	0.305
Competence in scientific methods and practices, specifically: Time management	60	0.087	61	0.352
Competence in scientific methods and practices, specifically: Note-taking	62	0.307	60	**0.604***
Competence in scientific methods and practices, specifically: Scientific report-writing	62	0.184	61	**0.351***
Ability to use mathematical concepts and skills in a practical context, for example, for data analysis	62	0.307	61	**0.515***
Ability to follow laboratory Health and Safety regulations	60	0.250	61	**0.393***
Ability to use IT tools in the laboratory or in the field, e.g. for making measurements	62	0.005	59	0.119
Ability to use IT tools for analysing and presenting data obtained in own experiments	62	0.156	61	0.121
Communication, team-working and presentation skills when working in a laboratory or in the field	62	0.125	60	0.206
Ability to use specialist laboratory and/or field work equipment	62	0.122	60	**0.457***
Ability to apply specialist methods and techniques when carrying out experiments or field work	62	0.027	58	**0.399***

$^*P<0.05$

Chemistry

As with biological sciences, HE staff teaching chemistry laboratory courses to first year undergraduate students considered the ability to follow laboratory instructions; follow health and safety instructions; and to understand laboratory and/or fieldwork instructions to be the most important skills for students to have on arrival at university in all three years of the study (Figure 67). In all three years HE staff did not consider students to be 'somewhat prepared' to 'very well prepared' in any of the 18 skills available to choose from. HE students considered themselves to be somewhat prepared in the majority of skills.

HE staff's perceived level of preparedness of students on arrival at university showed an increase year-on-year in eight of the 18 skills listed (Table 29). In years 1 and 2 of the study there was a strong positive correlation between the perceived importance of skills by HE staff and their estimation of students' preparedness in those skills (Table 66 in Appendix 3). This indicates that HE staff considered students to be best prepared in the skills which they rated as being most important. A moderate positive correlation was observed in year 3.

Figure 67. Chemistry: Perceived importance of skills and preparedness of students on arrival at university. Respondents were HE staff involved with the teaching of first year undergraduate laboratory courses. Scale - Preparedness: Year 1: 1 - Generally poor, 3 - Some capability, 5 - Well prepared. Years 2 and 3: 1 – Not at all prepared, 2 – Somewhat unprepared, 3 – Neither prepared nor unprepared, 4 -Somewhat Prepared, 5 - Very well prepared. Importance: 1 Very unimportant, 2 Quite unimportant, 3 Neither, 4 Quite important, 5 Very important (n = 55). 95% confidence intervals are indicated on the graph.

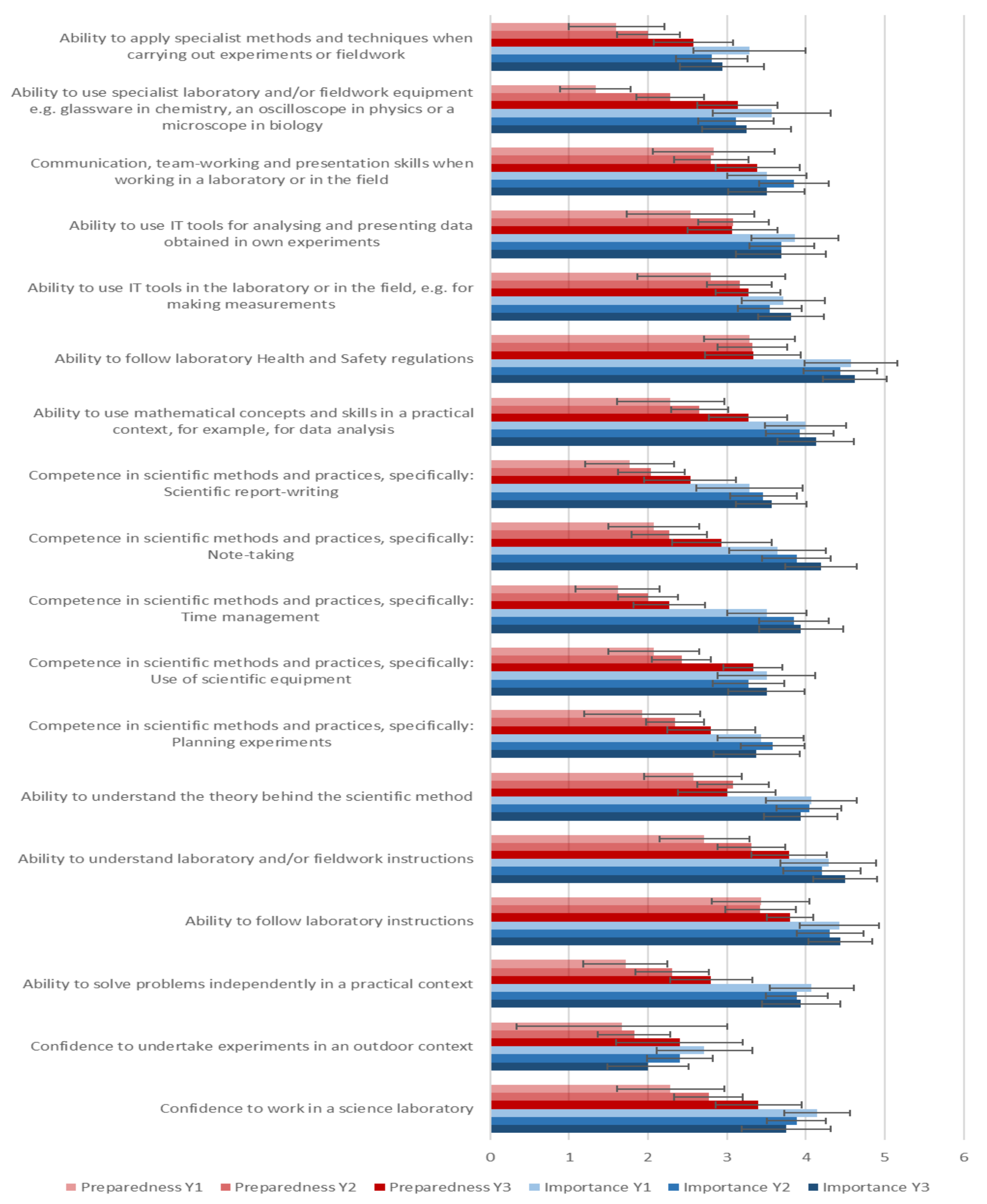


Table 29. Chemistry: Rate of change per year of the perceived importance of skills and preparedness of students. Respondents were HE staff from all three years of the study involved with the teaching of first year undergraduate laboratory courses. A statistically significant rate of change per year in the level of importance or preparedness over the three years of the study is highlighted in bold with the level of significance stated below the table. Note: the dependent variable in each case is the staff rating of the importance or preparedness for each skill. The rate of change per year is an estimate of the change per year in the Likert scale response over the 3 years of the study.

	Importance		**Preparedness**	
First year undergraduate skill	**n**	**Rate of change per year (five point Likert scale)**	**n**	**Rate of change per year (five point Likert scale)**
Confidence to work in a science laboratory	56	-0.195	55	**0.558***
Confidence to undertake experiments in an outdoor context	55	-0.358	25	0.403
Ability to solve problems independently in a practical context	56	-0.063	55	**0.542***
Ability to follow laboratory instructions	56	0.008	55	0.189
Ability to understand laboratory and/or field work instructions	55	0.113	54	**0.536***
Ability to understand the theory behind the scientific method	56	-0.068	55	0.210
Competence in scientific methods and practices, specifically: Planning experiments	56	-0.032	54	**0.439***
Competence in scientific methods and practices, specifically: Use of scientific equipment	56	0.007	54	**0.638***
Competence in scientific methods and practices, specifically: Time management	56	0.215	54	0.324
Competence in scientific methods and practices, specifically: Note-taking	56	0.273	54	0.436
Competence in scientific methods and practices, specifically: Scientific report-writing	56	0.137	54	0.386
Ability to use mathematical concepts and skills in a practical context, for example, for data analysis	56	0.067	55	**0.492***
Ability to follow laboratory Health and Safety regulations	55	0.032	54	0.024
Ability to use IT tools in the laboratory or in the field, e.g. for making measurements	56	0.056	50	0.220
Ability to use IT tools for analysing and presenting data obtained in own experiments	56	-0.082	53	0.255
Communication, team-working and presentation skills when working in a laboratory or in the field	56	-0.011	50	0.282
Ability to use specialist laboratory and/or field work equipment	56	-0.152	52	**0.897***
Ability to apply specialist methods and techniques when carrying out experiments or field work	56	-0.165	48	**0.493***

***P<0.05**

Physics

HE staff involved with the teaching of first year laboratory courses in physics showed different perceptions of importance to those in biological sciences and chemistry (Figure 68). In year 1 of the study, no skills had an average score that was ‘quite important’ to ‘very important’; by year 3, six skills were rated as ‘quite important’. Due to the number of respondents, the increase in level of importance was only significant for three skills over the course of the study. In all three years, there were no skills that HE physics staff considered students to be ‘somewhat prepared’ to ‘very well prepared’. HE physics students considered themselves to be ‘somewhat prepared’ in several areas, however, this was in notably fewer skills than biological sciences and chemistry students.

HE staff’s perceived level of preparedness of students on arrival at university showed an increase year-on-year in three skills (Table 30). In year 1 of the study there was a strong positive correlation between the perceived importance of skills by HE staff and their estimation of students’ preparedness in those skills (Table 66 in Appendix 3).

Figure 68. Physics: Perceived importance of skills and preparedness of students on arrival at university. Respondents were HE staff involved with the teaching of first year undergraduate laboratory courses. Scale - Preparedness: Year 1: 1 - Generally poor, 3 - Some capability, 5 - Well prepared. Years 2 and 3: 1 – Not at all prepared, 2 – Somewhat unprepared, 3 – Neither prepared nor unprepared, 4 -Somewhat Prepared, 5 - Very well prepared. Importance: 1 Very unimportant, 2 Quite unimportant, 3 Neither, 4 Quite important, 5 Very important (n = 43). 95% confidence intervals are indicated on the graph.

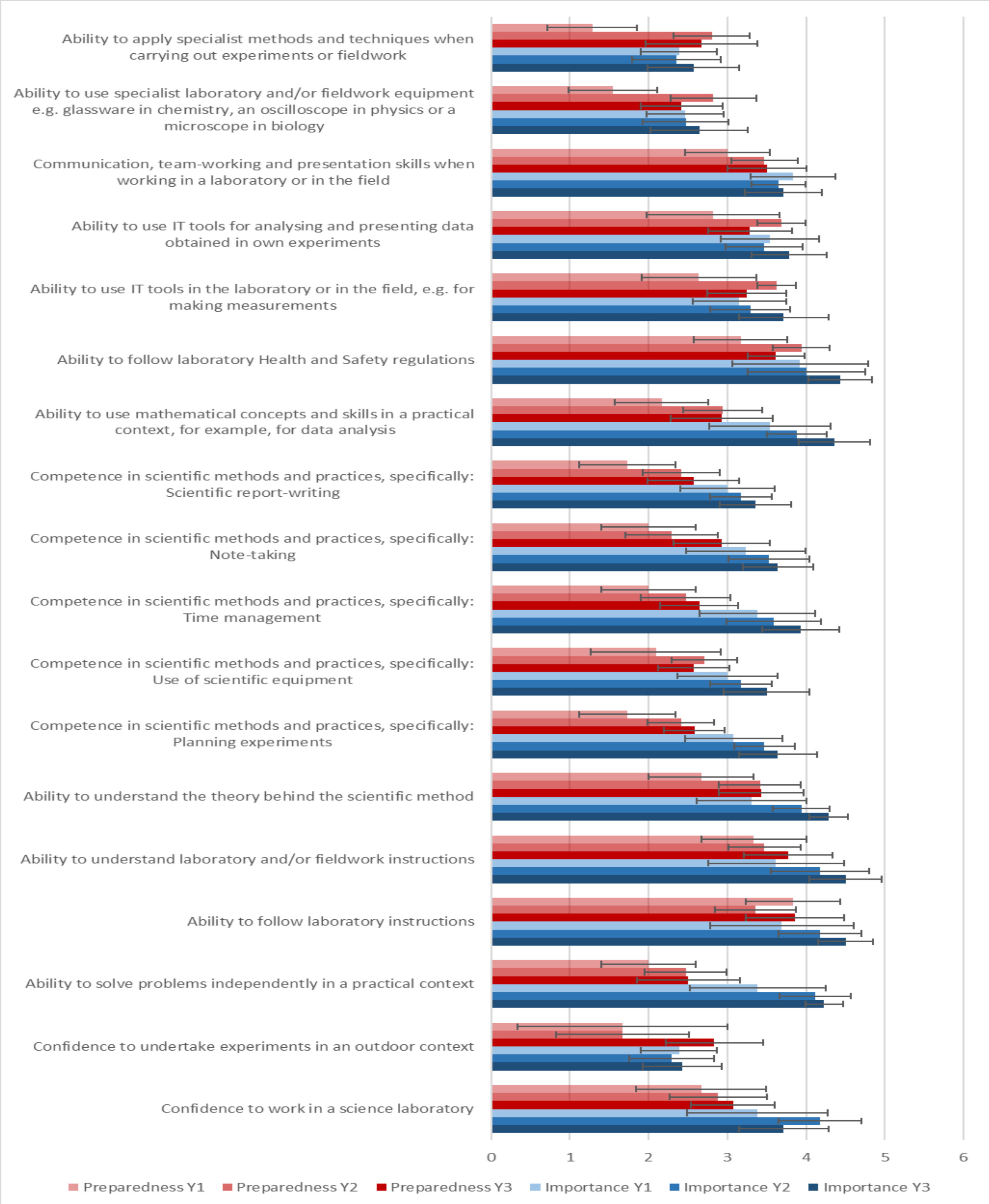


Table 30. Physics: Rate of change per year of the perceived importance of skills and preparedness of students. Respondents were HE staff from all three years of the study involved with the teaching of first year undergraduate laboratory courses. A statistically significant rate of change per year in the level of importance or preparedness over the three years of the study is highlighted in bold with the level of significance stated below the table. Note: the dependent variable in each case is the staff rating of the importance or preparedness for each skill. The rate of change per year is an estimate of the change per year in the Likert scale response over the 3 years of the study.

	Importance		Preparedness	
First year undergraduate skill	**n**	**Rate of change per year (five point Likert scale)**	**n**	**Rate of change per year (five point Likert scale)**
Confidence to work in a science laboratory	44	0.156	43	0.202
Confidence to undertake experiments in an outdoor context	44	0.024	15	0.667
Ability to solve problems independently in a practical context	43	**0.423***	43	0.243
Ability to follow laboratory instructions	44	0.403	43	0.027
Ability to understand laboratory and/or field work instructions	44	0.441	42	0.219
Ability to understand the theory behind the scientific method	44	**0.487***	43	0.370
Competence in scientific methods and practices, specifically: Planning experiments	44	0.281	40	**0.423***
Competence in scientific methods and practices, specifically: Use of scientific equipment	44	0.251	42	0.222
Competence in scientific methods and practices, specifically: Time management	44	0.273	43	0.317
Competence in scientific methods and practices, specifically: Note-taking	44	0.205	43	**0.469***
Competence in scientific methods and practices, specifically: Scientific report-writing	44	0.179	42	0.409
Ability to use mathematical concepts and skills in a practical context, for example, for data analysis	44	**0.410***	43	0.369
Ability to follow laboratory Health and Safety regulations	44	0.255	42	0.215
Ability to use IT tools in the laboratory or in the field, e.g. for making measurements	44	0.282	39	0.295
Ability to use IT tools for analysing and presenting data obtained in own experiments	44	0.126	41	0.204
Communication, team-working and presentation skills when working in a laboratory or in the field	43	-0.056	42	0.239
Ability to use specialist laboratory and/or field work equipment e.g. glassware in chemistry, an osc	44	0.092	40	0.420
Ability to apply specialist methods and techniques when carrying out experiments or field work	44	0.095	34	**0.591***

***P<0.05**

Comments from the HE staff telephone interviews agreed with the findings of the HE staff survey. In all three years, interviewees said that it was not necessary for students to arrive with any specialist technical skills (e.g. how to use an oscilloscope) as they would teach them everything that they would require once they were at university. HE staff wanted students to be able to operate in the laboratory safely, be enthusiastic and willing to ‘have a go’. Several departments reported designing their first year laboratory courses to help students build confidence and gain competence. Staff were willing to spend time working with students to get everyone to the same level early on in their degree programme.

Example: Preparedness for practical work at university

A common theme across respondents from all departments, and in all years of the study, was that students did not need to arrive at university with skills in using specialist equipment, but that they should have basic skills (especially the ability to follow health and safety instructions) and be willing to ‘have a go’.

> *“We have the facilities and experience to teach students to use pieces of equipment and can train them in practical techniques. So it is not so important that they arrive at university already able to do these things. More important in my opinion is the ability to study independently, take good notes, plan work, manage time (transferable skills which will make success at university more likely both inside and outside the lab).”*
>
> *Biological sciences – Interviewed in year 1 of the study*

> *“Some [skills], such as [more advanced] Health and Safety, we develop (i.e. to train them in glove protocol / handling toxics and corrosives) which are skills we do not expect them to have had the opportunity to develop in school, but simple 'wear your safety specs at all times, tie your hair up, wear your lab coat fastened with your sleeves down, wear sensible and appropriate footwear and clothing' are rules we expect them to be able to follow from day 1 after we have explained them. Many can't and don't.”*
>
> *Chemistry – Interviewed in year 1 of the study*

> *“Practical experience and knowledge they can gain in the first year because it is very much a playing field that is designed to be as level as possible. It is not designed to separate the students, it is designed to encourage them and catch them when they fall. So they can gain a lot of that in the first year but I would like them to be able to arrive here with sufficient skills that they don’t freeze.”*
>
> *Biological sciences – Interviewed in year 2 of the study*

The difference between education systems was also a reason for designing first year laboratory courses to bring all students to the same level and not requiring specific specialist skills on entry.

> *“We take on students from a wide variety of backgrounds and both national and international students and some students who have never done any practical work from European countries so we make sure we cater for all of these students in year 1.”*
>
> *Chemistry - HE staff survey in year 2 of the study*

Example: Experience of practical work before university

When asked what a good practical science experience was for students prior to arriving at university, HE staff commented that exposure to longer experiments, experience of independent working and having the opportunity to understand the rationale behind practical work would improve students' preparedness for university.

> *"A basic exposure to some things in the lab and the idea of what lab work will entail is important. Actually having or using specialist kit isn't as we can teach this. Having a scientific methodology to problems is important."*
>
> *Chemistry - Interviewed in year 1 of the study*

> *"I think something where they have some ownership of it rather than just doing pre-set exercises in the year but have had the opportunity to do some[thing] semi-independent... Maybe they have done [a] project in there and I think having…just experiencing a number of different technical approaches. I don't care what techniques they have done when they come in but when you've got ones who come in and basically have just thrown some quadrats around and that is not a holistic experience."*
>
> *Biological sciences – Interviewed in year 1 of the study*

> *"One thing that would be nice to have in the pre-university education, and I know it will never happen, is to give the students a couple of long experiments."*
>
> *Chemistry – Interviewed in year 3 of the study*

One of the largest barriers to students doing well in their first year laboratory courses was seen to be in students' perception that all practical work had to have a 'correct' answer.

Example: Student expectations of practical science at university

A common theme in all subjects and across all years of the study, was the expectation from students that practical work had a 'correct answer' and that laboratory demonstrators should provide students with the answer if they were experiencing difficulties with their practical work. HE staff also commented that the students only considered the work to be important if it contributed towards their final exam grades. HE staff frequently commented that they believed this stemmed from students' experience of practical work in their pre-university education.

> *"… a lot of students would come in with 'Oh practicals never work; practicals are rubbish' … mentality so we worked quite hard in our first term practicals to overcome that. I think there isn't necessarily a right answer [because] I think a lot of them are expecting that… 'Have I got the right answer? Is this data correct?' … and it is, 'Well did you do the experiment properly? Did you follow a robust protocol? And if so, that is your data'… a lot of them have that perception that there is just a right answer and that is not science."*
>
> *Biological sciences – Interviewed in year 1 of the study*

> *"Well there is a change in students, it is not recent but I mean there is a massive focus now on marks at schools and it is very evident. When I first started in this role students would ask to understand things but now they just want to know how they can get the marks which is a real shame."*
>
> *Chemistry – Interviewed in year 2 of the study*

> *"They come from high school with the conviction that there is a correct answer to the question and their task is to find the correct answer… That is the most difficult part that we have to make them unlearn – they say 'I know that it is this number so that if my experiment gives me a different number then it is wrong' and it is very hard to teach them that actually it is not necessarily… I can go through the technicalities but it is the philosophical point that is missing."*
>
> *Physics – Interviewed in year 2 of the study*

Only a small sample of HE students provided feedback on their post – 16 courses. None of the students reported that their post- 16 education had prepared them 'very well' for laboratory courses and/or fieldwork in their first year at university. However, biological sciences and chemistry students were more positive than physics students. A small proportion of the first year undergraduate students reported experiencing laboratory of fieldwork activities in which they felt unable to do well because they didn't have the right practical skills in their first term at university.

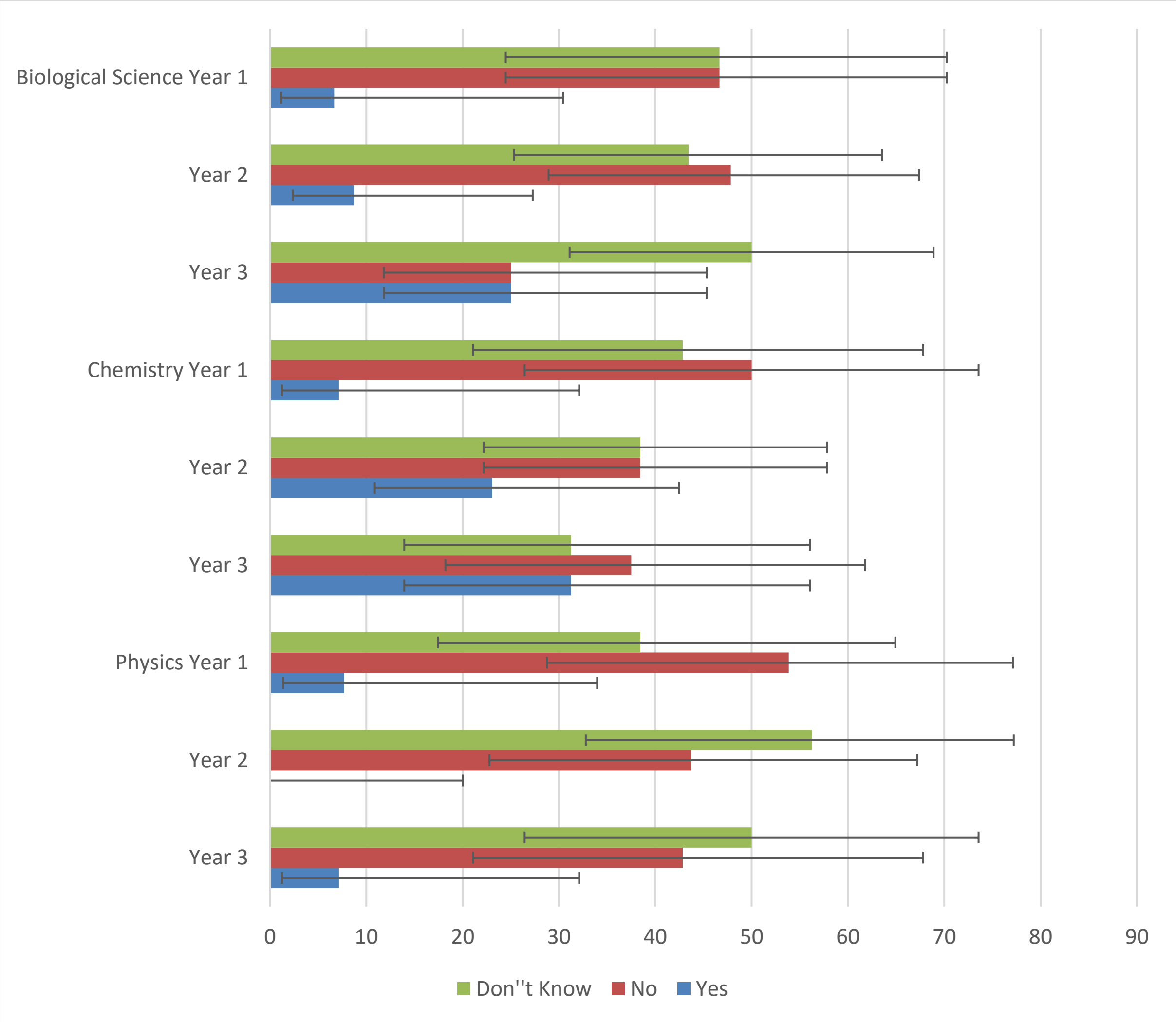
Whether students had participated in any additional training and qualifications (e.g. Extended Project Qualification (EPQ), CREST Award, Duke of Edinburgh Award) before entering university did not affect how well prepared students felt. The future aspirations of students (e.g. whether they were considering a career in science or a science-related degree or whether they were hoping to carry out an independent research project as part of their degree) also had no impact on how well prepared the students felt on arrival at university.

Impact of pre-university training and qualifications

HE staff expressed mixed opinions as to whether they assume that a good grade in A levels (or equivalent) reflects a level of practical skill which will enable the student to fully access the course for which s/he has applied, with no difference observed between the percentage of staff stating yes or no (Table 67 in Appendix 3 and Figure 74 in Appendix 3).

HE staff were also asked whether their department currently takes into account an applicant's Extended Project Qualification (EPQ) or CREST Award/Nuffield Research Placement experience in their entry requirements (Figure 69 below and Table 68 in Appendix 3). In biological sciences in years 1 and 2 of the study, chemistry in year 1 of the study and physics in all three years of the study, fewer than 10% of respondents indicated that they are taken into account by their department. However, biological sciences in year 3 of the study and chemistry in years 2 and 3 of the study showed higher percentages of respondents indicating that they were taken into account.

Figure 69. Bar chart showing respondents' response as to whether their department currently takes into account an applicant's Expended Project Qualification (EPQ) or CREST Award/Nuffield Research Placement experience in their entry requirements (Biological sciences n = 62, chemistry n = 56, physics n = 43). Respondents were higher education staff. 95% confidence intervals are indicated on the graph.



HE staff were asked whether their department requires a pass in a practical endorsement alongside any science A levels (or equivalent) (Table 31). In year 1 of the study, the majority of respondents did not know whether the practical endorsement was going to be a requirement. However, over the course of the study there was an increase in the percentage of respondents stating that the practical endorsement was not a requirement alongside any science A levels (or equivalent) in biological sciences and chemistry.

Table 31. Respondents' responses as to whether their department requires a pass in a practical endorsement alongside any science A levels (or equivalent). Respondents were higher education staff. Statistically significant rates of change per year are highlighted in bold with the level of significance stated below the table.

	Year 1		Year 2		Year 3		Rate of change (logits per year)
	n	%	n	%	n	%	
Biological sciences							
Yes	15	0.0	23	21.7	24	0.0	-0.26
No		26.7		56.5		70.8	**0.92***
Don't know		73.3		21.7		29.2	**-0.87***
Chemistry							
Yes	14	14.3	26	19.2	16	31.3	0.53
No		7.1		57.7		50.0	**0.90***
Don't know		78.6		23.1		18.8	**-1.48***
Physics							
Yes	13	7.7	17	17.6	14	28.6	0.75
No		30.8		41.2		50.0	0.40
Don't know		61.5		41.2		21.4	**-0.88***

***P<0.05**

Durham University

Importance and reasons for practical work in undergraduate science degrees

From an open question asking the reasons why they thought practical work was important within science degrees, HE staff who participated in qualitative telephone interviews stated four common themes. These were: accreditation requirements; employability skills; reinforcing knowledge; and understanding the world through experimentation and observation.

HE staff were also asked for the reasons they undertook practical work in their first year undergraduate courses. Staff again stated four common themes which were to improve students': skills; scientific knowledge and thinking skills; communication; and health and safety.

Example: Importance and reasons for undertaking practical work in undergraduate degree courses – Developing skills and knowledge

Staff emphasised the importance of practical work in undergraduate laboratory courses for developing skills specific to practical work as well as for reinforcing skills and knowledge acquired as part of the wider degree course.

> *"[Practical work] helps to reinforce knowledge; it helps to teach information in a different way… I think it is kind of problem based learning … the lab is the ultimate base learning situation. It is also something different from traditional lectures, a way of reinforcing lecture material, or … [for] teaching things completely separately."*
>
> *Chemistry - interviewed in year 1 of the study*

> *"Our first year lab course doesn't count towards the degree […] The whole point of our first year course is to get everybody up to the same theoretical and practical level."*
>
> *Chemistry - interviewed in year 2 of the study*

> *"We have learning outcomes which are related to development of specific practical skills. You would be able to set up experiments and … we … have the subject learning objectives but we also make it very clear to the students of the other objectives as well. So it is about skill teaching as well as subject teaching."*
>
> *Biological sciences - interviewed in year 1 of the study*

> *"We have looked at writing and the academic skills and not just per year but across the board so how does a student develop as they go through and where do they need to be at the end rather than just thinking that they should just write some lab reports because that is what they need to do. It is actually what is it that they need to write and what are the outcomes there and how do we develop that and making a structure, a scaffold that has stepwise changes that allows the student to develop and also allows them to consolidate skills."*
>
> *Chemistry - interviewed in year 2 of the study*

8.3.2.1 Change due to A level reforms

Higher Education staff knowledge about reforms

Higher Education staff participating in qualitative telephone interviews were asked how much they knew about the reforms to the GCSE and A level curricula in England and what their views on the changes were.

Example: Knowledge of reforms to GCSE and A level

Participants commented that knowing the details of the reforms was difficult outside the school system.

> *"It is one of these frustrations in that the A levels obviously keep changing and we are not school teachers and we don't keep up to date with the syllabuses, and it is not one we need to keep up to date with but five different boards and they are all subtly different. I know [colleague at another HEI] has a great big table of everything at A level and which boards cover what and in what depth but that is a monumental document to try and keep up to date."*
>
> *Chemistry – interviewed in year 2 of the study*

Example: Views of Higher Education staff on the impact of the changes to the A level curriculum in England

In year 2 of the study (before the first cohort of students studying the new curriculum had entered university), there was a feeling that the changes would devalue practical work and reduce student preparedness.

> *"I am expecting a big decline in preparedness for lab work in 2017 entry, when the new assessment (or lack of assessment) for practical at A level will have had an impact."*
>
> *Chemistry – year 2 HE staff survey*

> *"The reasons they were taken out of the main one was because of problems with the marking of the experiments so I understand why it has been taken out and I don't think that is the correct decision personally. I think it devalues in the mind even if it doesn't actually…even though they have questions in the exam what the practicals should be."*
>
> *Physics – interviewed in year 2 of the study*

In year 3 of the study (mid way through the first term at university for the first cohort of students to have been examined under the new A level curriculum), some staff were still waiting to see how the changes impacted their students.

> *"I was really hoping that it would, you know…I am a big fan of the changes they have made at A level and I think it has really improved A level. […] Mine are very bright students and so I think any changes like that would be less easy to see in the higher ability students."*
>
> *Chemistry – interviewed in year 3 of the study*

Example: Views of Higher Education staff on the impact of the changes to the A level curriculum in England

For HE staff who had already begun teaching undergraduate students who had been taught under the new A level curriculum in England, staff from different universities were able to give specific examples of the impact that the changes were having.

> *"None of them had ever done a lab report.[…] I have got a great relationship with the main sixth form college in [name] and I go up there once every two weeks. […]I asked one of the chaps if students write lab reports […] and he showed me in the lab book two pages of lined paper where students jot down their observations and that is called a lab report. So, of course, when they got here they are writing it in third person passive tense which was completely new to them and the different sections were new to them…what was the difference between results and analysis and discussion kind of thing and so that has been the biggest issue for them."*
>
> *Chemistry – interviewed in year 3 of the study*

> *"I asked one of the students who had gone to a pretty good school in England how was it and how did it compare to sixth form and he said it is completely different because we actually did the experiment here…and I know that the whole endorsement thing is supposed to reflect the students having done the labs themselves but the huge response I get from the students and the teachers is that there are so many [experiments] where either the teacher is doing the lab as a demonstration and the whole data logger thing comes up frequently in that regard or the students are working in such big groups that they really don't get the hands on experience that one would want and of course I know this is completely against the whole ethos of the lab endorsement."*
>
> *Chemistry – interviewed in year 3 of the study*

> *"This year […], more than one actually, there has been a couple of students who have told me exactly that in different lab groups […] As they had to do melting points but they didn't have melting point apparatus, so they sello-taped some melting point tubes to a thermometer and waving it in a Bunsen Burner to try doing it. […] School resourcing is definitely a problem and I think the concept is good with what we are trying to do with schools now and the A level changes and I think we are going in the right direction. I think there probably needs to be some more attention to detail with what is actually realistic for a school and supporting the schools with the resources they need and even more importantly supporting the teachers with the training they need."*
>
> *Chemistry – interviewed in year 3 of the study*

8.3.2.2 Adjustments to Higher Education curriculum content and teaching

HE staff were asked whether their department had made adjustments to curriculum content and teaching to accommodate students' practical work skills and knowledge on transition from post – 16 education. In the first year of the study, respondents were asked to comment on changes in the previous five years. In years 2 and 3, respondents were asked to consider changes since the previous academic year. In all three years of the study in all subjects, changes being made to laboratory based teaching was reported by the highest (or equal highest) percentage of respondents (Table 32).

Table 32. Percentage of respondents reporting a change in laboratory based undergraduate teaching in response to the practical work skills of new first year undergraduate students. In year 1 of the study, respondents were asked to consider whether there had been a change in laboratory based teaching over the previous 5 years. In years 2 and 3 of the study, respondents were asked to consider change since the previous academic year. Respondents were HE staff involved with the teaching of undergraduate laboratories and could choose more than one area in which changes had been made. 95% confidence intervals are indicated in brackets.

	Year 1		Year 2		Year 3	
	n	%	n	%	n	%
Biological sciences						
Laboratory-based teaching changed		47(24,70)		35(19,56)		29(15,50)
Reduced the number of laboratory experiments		13(4,38)		13(4,33)		8(2,26)
Increased the number of laboratory experiments		7(1,30)		9(2,27)		8(2,26)
Removed complex experiments		20(7,46)		13(4,33)		4(1,21)
Introduced complex experiments	15	0(0,21)	23	4(1,21)	24	0(0,14)
Included detailed instructions on basic techniques		33(15,59)		30(15,51)		25(12,45)
Reduced instructions on basic techniques		0(0,21)		0(0,15)		0(0,14)
Changed curriculum content		47(24,70)		13(4,33)		13(4,31)
Other		0(0,21)		13(4,33)		0(0,14)
Chemistry						
Laboratory-based teaching changed		71(45,88)		56(37,74)		44(23,67)
Reduced the number of laboratory experiments		14(4,41)		20(9,40)		13(3,37)
Increased the number of laboratory experiments		7(1,32)		12(4,30)		6(1,29)
Removed complex experiments		21(7,48)		12(4,30)		0(0,20)
Introduced complex experiments	14	14(4,41)	25	12(4,30)	16	0(0,20)
Included detailed instructions on basic techniques		64(38,84)		36(20,56)		13(3,37)
Reduced instructions on basic techniques		0(0,22)		12(4,30)		6(1,29)
Changed curriculum content		29(12,55)		20(9,40)		31(14,56)
Other		36(16,62)		20(9,40)		13(3,37)
Physics						
Laboratory-based teaching changed		62(35,83)		38(18,62)		21(7,48)
Reduced the number of laboratory experiments		8(1,34)		0(0,20)		0(0,22)
Increased the number of laboratory experiments		15(4,43)		6(1,29)		0(0,22)
Removed complex experiments		31(12,58)		6(1,29)		0(0,22)
Introduced complex experiments	13	8(1,34)	16	0(0,20)	14	0(0,22)
Included detailed instructions on basic techniques		38(17,65)		13(3,37)		7(1,32)
Reduced instructions on basic techniques		0(0,24)		6(1,29)		0(0,22)
Changed curriculum content		23(8,51)		13(3,37)		0(0,22)
Other		0(0,24)		19(6,44)		21(7,48)

8.3.2.3 Changes to undergraduate ability and understanding

Higher Education staff were asked to report on their perceived change in first year undergraduates' skills, knowledge and understanding on arrival at university over the last five years (in year 1 of the study) and since the last academic year (in years 2 and 3 of the study). Due to the small sample size for the data in this section, it is important that care is taken not to over-interpret the findings.

Over the three years of the study in biological sciences, an increased percentage of HE staff reported a decline in the level of knowledge of students (Figure 70 below and Table 69 in Appendix 3), where level of knowledge was described as 'referring to familiarity with different topic areas within their subject'. However, it should be noted that the number of respondents was small.

In chemistry over the three years of the study, there was a decrease in the percentage of respondents reporting a decline in skills for: laboratory skills (defined as 'the ability to work with apparatus effectively - not including experimental planning or data analysis etc'); ability to plan experiments in the laboratory; and ability to work independently in the laboratory (Figure 71 below and Table 70 in Appendix 3). This was combined with an increase in the percentage reporting an improvement in laboratory skills.

In physics over the three years of the study, an increase was observed in the percentage of respondents reporting that the level of skills has stayed about the same for: laboratory skills and level of understanding (Figure 72 below and Table 71 in Appendix 3). A decrease was observed in the percentage of respondents reporting a decline in laboratory skills over the course of the study.

Figure 70. (Biological sciences) Stacked bar chart showing respondents' perception of changes to first year undergraduates' skills in the previous 5 years (year 1 of the study), and since the last academic year (years 2 and 3 of the study) (n = 62). Respondents were HE staff. 95% confidence intervals are indicated on the graph.

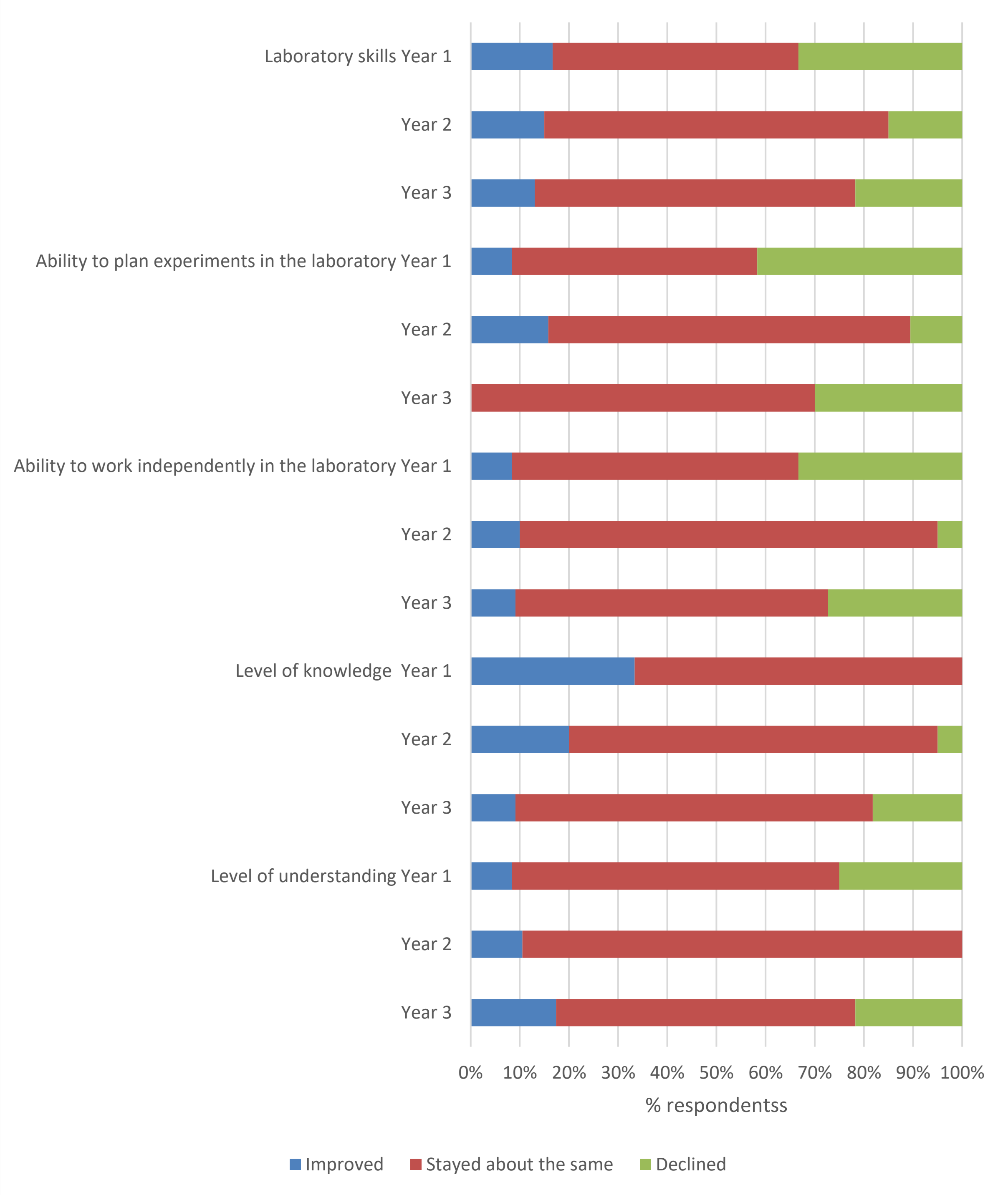


Figure 71. (Chemistry) Stacked bar chart showing respondents' perception of changes to first year undergraduates' skills in the previous 5 years (year 1 of the study), and since the last academic year (years 2 and 3 of the study) (base n = 56). Respondents were HE staff. 95% confidence intervals are indicated on the graph.

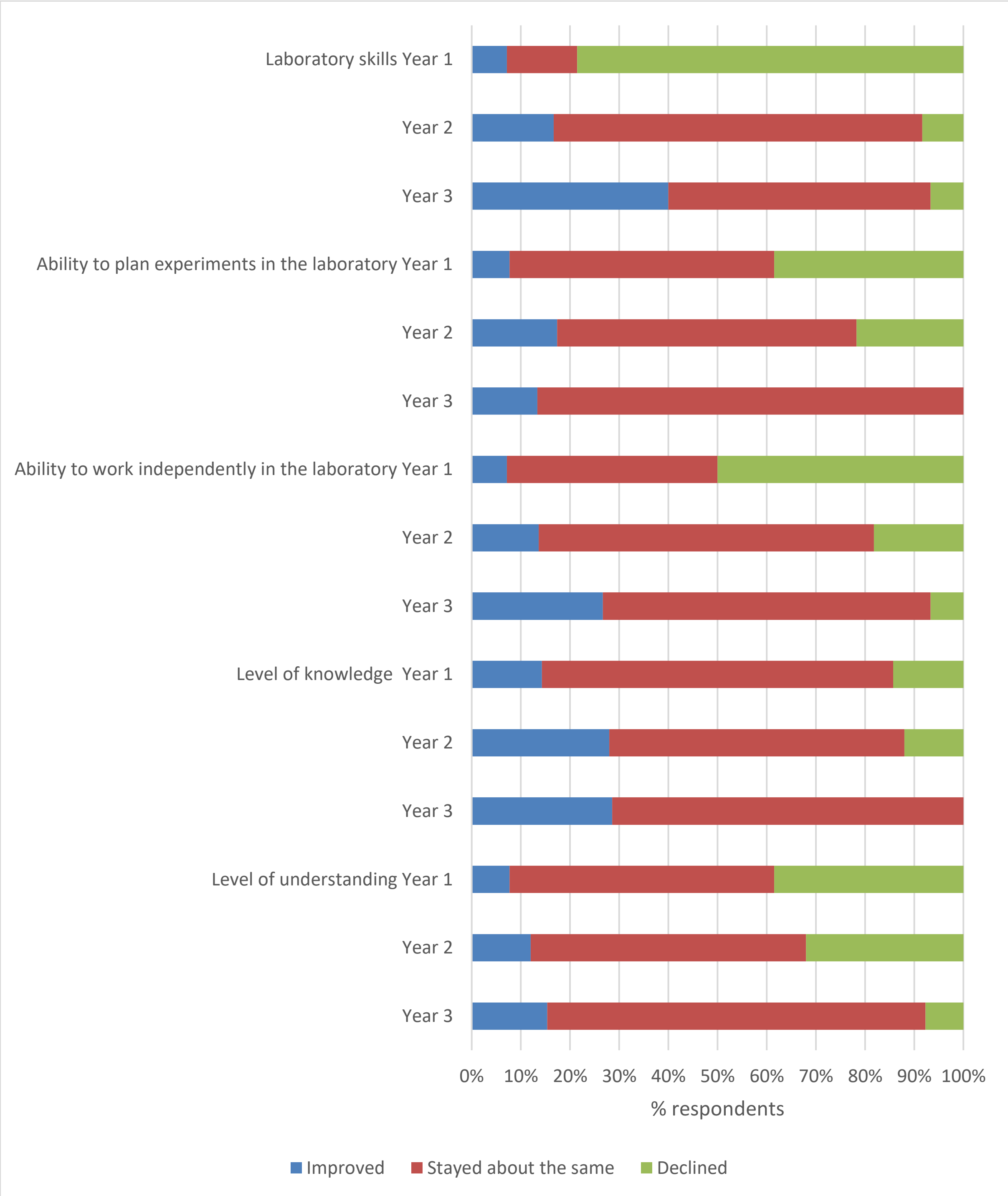
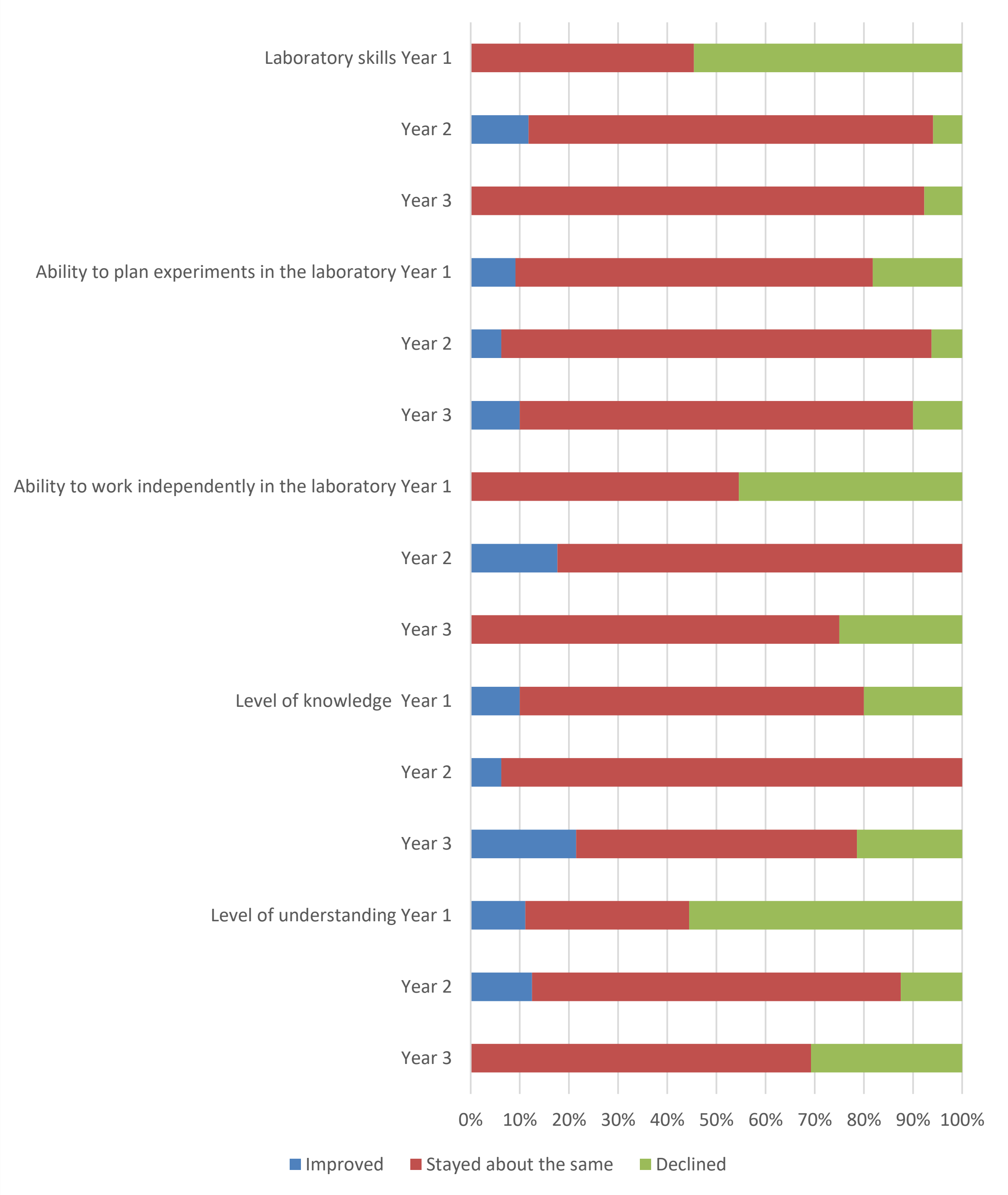


Figure 72. (Physics) Stacked bar chart showing respondents' perception of changes to first year undergraduates' skills in the previous 5 years (year 1 of the study), and since the last academic year (years 2 and 3 of the study) (n = 44). Respondents were HE staff. 95% confidence intervals are indicated on the graph.



9 Discussion

The discussion is presented in two sections. The first summarises and discusses responses to the research questions:

1) What science practical work is provided within schools in terms of the quantity and breadth undertaken and how has this changed over the lifetime of the study?
2) What are the main insights into any influences on the quantity and breadth of science practical work undertaken in schools?
3) How does practical science contribute to preparing students for their next steps in science education?

The second section addresses issues arising from these responses. These are areas of strength and weakness in practical work provision; and matters of concern arising from the data for schools in both England and Scotland. Before concluding, topics of future interest for research in this field are proposed. As has been previously noted, findings should be interpreted with consideration that the sample of heads of science and science teachers participating in this study were more highly qualified than the overall workforce.

9.1 Responses to the research questions

9.1.1 What science practical work is provided within schools in terms of the quantity and breadth undertaken and how has this changed over the lifetime of the study?

As indicated above, the quantity and breadth of practical work within schools were determined from responses provided by heads of science and science teachers. The following section offers a brief summary of the outcomes.

Quantity of practical work

Respondents reported the timetabled time per week for science lessons and the amount of time per week within science lessons they estimated was spent on practical work. Lesson time increased across the three age-ranges (11 – 14, 14 – 16 and post – 16), with post – 16 students spending approximately five hours a week in lessons for a particular science subject. In England, the number of hours spent on practical work within science lessons was also higher in the post – 16 age range than in the 11 – 14 or 14 – 16 age ranges. However, in Scotland the number of hours spent on practical work within science lessons was similar across the three age ranges. There were no systematic (e.g. for all subjects or for all school types) changes over the period of the study in the timetabled time for science lessons, or the time spent in science lessons on practical work.

The average proportion of science lesson time spent on practical work was calculated from the timetabled time per week for science lessons and the amount of lesson time per week spent on practical work. In England and Scotland, practical work for 11 – 14 year old students occupied one-third to two-fifths of science lessons. For 14 – 16 year old students and post – 16 students, practical work occupied one-fifth to one-third of science lesson time per week. No systematic (for all subjects or all school types) change occurred to these values . However, for specific groups, statistically significant changes to the proportion of science lesson time spent on practical work occurred over time. These were:

- An increase for 11 – 14 year old students in chemistry in English independent schools. However, it should be noted that this may be accounted for by a decrease in science lesson time, rather than an increase in the amount of lesson time spent on practical work.

- An increase for 11 – 14 year old students in physics in English independent schools. However, it should be noted that this was not associated with a significant increase in the amount of lesson time spent on practical work nor a significant decrease in overall lesson time.
- An increase for 11 – 14 year old students in science in English state schools. However, this was also not associated with a significant increase in the amount of lesson time spent on practical work or a significant decrease in overall lesson time.
- An increase for 14 – 16 year old students in biology in English state schools which corresponded to a significant increase in the number of hours of lesson time spent on practical work and no significant decrease in overall lesson time. The number of practical work activities carried out by students during an academic year also increased over the course of the study.
- A decrease for post – 16 students in biology in English independent schools. However, this was not associated with a significant decrease in the amount of lesson time spent on practical work or a significant increase in overall lesson time.

Ofqual (2018) investigated post – 16 practical work time by surveying biology, chemistry and physics students at the start of their undergraduate science degrees in Autumn 2016 (pre-reform) and 2017 (post-reform). Students were asked to reflect on their experiences during their A level science qualifications. Their data showed the majority of students reporting to have carried out practical work less than once each week during their A level studies. An increase between pre and post reform in the frequency with which biology and physics students reported undertaking practical work in their A level studies was found. Although possibly contradictory to our findings, there are differences in sample and question phrasing between the two studies. Ofqual utilised a question format which permitted student respondents to select from a range of practical work frequency options, but did not ask for the length of practical work time to be specified. Our study asked teachers to estimate a number of hours for practical work in science lessons, assuming practical work was carried out weekly. Students self-report in the Ofqual study; compared to teachers and heads of science in our study. Differences are likely between schools from which the two samples are drawn. Our data reveal a wide range of practical work post – 16 time. The sample in the Ofqual study (2018) may be drawn from schools which offer practical work with relatively high frequency. We observe that our data concur with Wilson (2016), in which most respondents indicated that student practical work occupied 21 – 40% of A level biology, chemistry and physics teaching time. Wilson (2016)'s data were collected in summer 2015 (pre-reform) from teachers in schools broadly similar to those registered for OCR (Oxford and Cambridge[9]) science qualifications (over-representation of independent schools is acknowledged in their study).

Breadth of practical work

Data indicate consistency in the type of practical work offered to all students throughout the lifetime of the study. Practical work that required students to "follow prepared instructions" was most common for all students in state and independent schools in England and Scotland, supporting the findings of Wilson (2016). "Analysing data" was the next most frequent task undertaken. At post – 16, these two tasks showed slight variations in frequency: for biology, following prepared instructions and data analysis occurred with equal frequency; for physics, analysing data occurred more frequently than following prepared instructions.

In general, these findings point to a constant commitment in an overwhelming majority of schools to provide practical work experiences for students that they carry out themselves. Within science lessons, the least frequent activity undertaken (from a choice of practical work, teacher demonstrations and computer simulations) was using computer simulations. We were intrigued to

[9] https://www.ocr.org.uk/

find out if frequencies of these increased post-reform, as concern was expressed prior to the study regarding use of teacher demonstrations and computer simulations as possible substitutes for students' "hands-on" experiences. Respondents reported use of computer simulations for less than 8% of lesson time per week. Two significant changes were observed in the frequency with which computer simulations were used. First, an increase was observed in the 14 – 16 age range in biology in state schools. Second, a decrease was observed for the post – 16 age range in chemistry in state schools. These findings may arise due to differences in levels of knowledge and expertise regarding application of computer simulations among respondents between survey years and/or the availability of IT equipment in science laboratories. Additional data are required to investigate this thoroughly.

Teacher demonstrations were reported to be used in less than 21% of lesson time per week in England and Scotland. Over time, in the 11 – 14 age range in independent schools, an increase in teacher demonstrations was observed in chemistry.

Opportunities to carry out long-term, extended practical work seem limited to specific student sub-sets. In the post – 16 age range, this opportunity is provided by about 85% of English state school respondents for physics and 70% of Scottish state school respondents (all subjects combined). Lower frequencies are observed in the 11 – 14 and 14 – 16 age ranges, as about 15 – 20% of English state school respondents, 20 – 40% of Scottish school respondents and 5 – 18% of English independent school respondents offer long-term practical work for these age groups. From respondents in English state schools, 26 - 32% reported having facilities for long-term extended practical work. This figure was 50 – 52% in independent schools and 22% in year 3 of the study in Scotland.

These data suggest that despite variations in school locus and type, practical work breadth is limited. Students of all ages most frequently experience short-term, "hands-on" practical work, or analyse data obtained in an experiment in a previous lesson. Practical work tends to be completed within one science lesson. An added observation arises from qualitative data. Post-reform, these show that as well as teachers reporting improved integration of practical work into A level programmes, the reforms have also resulted in perceptions of a higher status for practical work by the students and school senior management. This is perhaps surprising given that the reform, in removing the coursework component, also removed direct contribution of practical work to students' final grades.

9.1.2 What are the main insights into any influences on the quantity and breadth of science practical work undertaken in schools?

In answering this question, data relating to a range of factors were collected in anticipation of changes to the quantity and breadth of practical work offered. Teacher and school-related factors were: teacher qualifications; availability of technical support; quality of facilities for science; the equipment available; departmental budgets; and examination specifications. Student and societal factors were examined by exploring correlations between the proportion of science lesson time spent on practical work and social deprivation. Although changes in quantity and breadth of practical work were minimal, data collected offer insights into the ongoing condition of science practical work in schools in England and Scotland.

Teacher and school-related factors

Teachers and technicians

In general, respondents to our survey are well qualified for teaching science to students in each of the three age groups. However, caution is advised, as the likelihood is that the respondents are better qualified than the science teaching workforce nationally (Gov.uk, 2018). Hence, while these outcomes are reliable for these samples, they may not be truly representative of the position for all science provision in schools in England and Scotland.

Heads of science provided information about the level of technical support available. A potential consequence from the reform was reduction in technical support, as loss of coursework in GCSEs and A levels may have been perceived as requiring less technician time. Our data suggest the average number of FTE technicians employed in each school remained constant. Nevertheless, some schools reported a decline in technical support in year 3 for financial reasons, while about 10% indicated an ongoing technician vacancy.

The nature and amount of technical support varies by school type. In English state schools the average number of FTE technicians per 100 students is around 0.25; in Scottish state schools this is about 0.18; and independent schools, about 0.50. Over 70% of technicians in independent schools regard themselves as “subject specialists”, compared to 34% in English state schools. Thus, although support for standard curriculum provision seems constant across all schools, where technical support permits, extra-curricular science clubs and extended project qualifications (EPQs) involving data collection may be possible. Data were not collected about science teaching conducted outside normal classroom hours (e.g. in school holidays).

Data supplied by technician respondents indicate they carry out many tasks with varying frequency. These tasks did not change from year 1 to year 3 of the study. Unsurprisingly, about two-thirds of technicians reported setting up equipment for an experiment as a daily task. About one-third offer daily advice to teachers on how to carry out an experiment; and about half discuss curriculum specification requirements with teachers either daily or weekly. These and other data indicate high professional value ascribed to technicians as part of a team delivering science in schools. However, these are counter-balanced by lower level tasks such as photocopying, filing and moving books and furniture. Maximising technician time spent on supporting practical work and minimising other tasks may be valuable.

Heads of science commented on their satisfaction with the level of technical support. About two-thirds of English state and around three-quarters of English independent school heads of science were satisfied or very satisfied. About one-quarter in English state and around on-tenth in English independent schools were dissatisfied or very dissatisfied. No changes occurred in three years. Unfortunately, a low response rate from heads of science in Scotland means that similar findings cannot be reliably reported. In English state and independent schools, the numbers of FTE technicians correlate positively with heads of science levels of satisfaction. Taking each school sub-set separately shows a slight variation: in English independent schools, a negative correlation was observed between higher student: technician ratios and heads of science satisfaction; this correlation was not found in English state schools. Overall, these data may indicate that although heads of science in English state schools are less satisfied with the level of technical support than their independent school counterparts, all respondents appreciate the importance of technicians in efficient delivery of practical work.

Facilities, equipment and budget

Prior to the study, interest was expressed in changes to the numbers of science laboratories, in case removal of coursework post-reform prompted re-purposing of these rooms. Technicians provided information about the numbers of laboratories and the equipment available in years 1 and 3 of the study. Data show that in English state schools, the overall school student: laboratory ratio is about 200:1; in English independent schools this is about 100:1; and in Scotland, about 100:1. Most laboratories seem well-furnished and have basic facilities, including utilities, whiteboards and health and safety equipment. One-third of all respondents from state schools in England stated all their laboratories were appropriate for the class sizes that used them, increasing to half of respondents in independent schools in England and almost two-thirds of respondents from state schools in Scotland.

Conversely, in year 3 of the study, one-fifth of respondents state schools in England reported that up to half of laboratories were not appropriate for the class sizes that used them. The number reduced to one-tenth of respondents from independent schools in England and one-twentieth in state schools in Scotland.

Accessibility for SEND students was explored in year 3 of the study. Over three-quarters of respondents from state schools in England and just under three-quarters of respondents from independent schools in England and state schools in Scotland reported most or all of their laboratories were accessible to Special Educational Needs and Disability (SEND) students. This means that approximately one-quarter of schools had facilities that were not accessible to SEND students. Qualitative data suggest that not all schools may be able to purchase equipment required to deliver all practical work examples cited in the new curricula specifications. Overall, however, respondents' schools have not reduced the number or altered laboratories in the light of the qualification reform, suggesting investment in facilities for practical science seems constant. These figures are consistent with the Good Practical Science report (Gatsby, 2017).

Less favourable findings relate to "specialist" facilities. For example, in years 1 and 3 over one-half of English state and independent school respondents indicated that only a few, or none of their laboratories had student computers. About two-thirds of technicians never set up IT equipment, in part because this is not routinely available in laboratories. About one-sixth of respondents in year 3 reported that all laboratories had space for long-term extended investigations/experiments. This is lower than the 28% reported by Gatsby (2017). These figures corroborate the findings discussed above: that the vast majority of practical work utilises basic equipment that require students to follow instructions.

Preparation rooms act as a main locus of activity in school science departments, impacting the ease with which teachers and technicians can deliver high quality practical work. Thus, technicians were asked about these. First, we note that data show variation in the number of preparation rooms by school type: typically, in whole numbers, English state schools have two or three; English independent schools have three; and Scottish schools one or two. Next, English independent schools report that about two-thirds of preparation rooms are subject specific, consistent with their technicians being employed as specialists. In English state schools, about two-thirds of preparation rooms serve all sciences, aligning with their technicians as generalists. In Scotland, more than four-fifths of preparation rooms are general. Third, the ratio of laboratories to preparation rooms varies. In English independent schools, this is about 3.3:1; in English state schools, about 4.5:1; and in Scottish state schools, about 7.2:1. Together, these data show variability in provision by school type and UK nation. Provision in Scotland seems less favourable than in England, although we express caution here as the Scottish sample was small. In England, the state / independent sectors adopt different emphases. Independent sector respondents show a focus on specialist sciences throughout. State sector responses show science is regarded most often as combining biology, chemistry and physics. Possible implications arising are discussed later.

An issue noted prior to the study was the potential for reductions in levels of resource post-reform, due to perceptions that new curricula required less resource than those with a coursework component. Accordingly, heads of science were asked about the financial resources ("budget") available to spend per student each year. In English state schools, the mean budget was £11 or £12 per student; English independent schools, £33 - £37; and in Scottish schools, £4 (year 1 of the study) and £6 (year 3 of the study). Figures were constant during the study. The survey asked only for the amounts available to spend, not how resource was allocated. Thus, variation may arise due to the range of expenditure items available to heads of science. For example, higher figures may include continuing professional development costs; equipment repair; photocopying; and textbook purchase.

We note, however, that heads of science in English independent schools reported significantly higher average satisfaction with their budgets than their state school counterparts. Data presented elsewhere show consistency in the type of practical work offered in all schools, so higher budgets are not an automatic indicator of greater variation or, potentially, higher quality provision. A factor that relates to this at least to some extent, and may over-ride relatively small budgets, is that heads of science strongly believe their teachers have sufficient competency to carry out high quality practical work.

Overall, these data show that a majority of school science practical work takes place in purpose-built facilities with good access to basic equipment, serviced by technical support with findings comparable to those recommended in the Good Practical Science Guide (Gatsby, 2017). No significant changes in these factors are reported. These are clear strengths of current provision. Nevertheless, there are distinct variations, particularly in the style of provision between state-funded and independent schools. This has consequences for how practical science is serviced via technician positions and preparation rooms. We identify significant variation in financial resource availability between the independent and state sectors. However, no factors changed significantly during the study, suggesting that, overall these factors have not impacted on the quantity and breadth of practical science post-reform.

Societal and student factors

The extent to which social deprivation may impact students' accessing practical was probed via correlation analysis of the proportion of science lesson time spent on practical work with the Income Deprivation Affecting Children Index (IDACI) score (for the school) and the proportion of students receiving Free School Meals (FSM). A statistically significant negative correlation between IDACI score and proportion of lesson time spent on practical work was observed in the 11 – 14 age range and 14 – 16 age range in year 1 only i.e. in year 1 of the study, schools with higher levels of deprivation spent a lower proportion of lesson time on practical work. This concurs with the Wellcome Trust Science Education Tracker (2017). No correlations between IDACI and proportion of science lesson time spent on practical work were found in years 2 and 3. No correlations were found in any year between the proportion of lesson time spent on practical work and proportions of pupils eligible for FSM. These data offer a small hint that social deprivation may contribute to poorer experiences of science in school for students experiencing poverty, but this is not clear cut.

Qualitative data suggest a consensus that students find practical work motivating, acting as a positive factor when deciding post – 16 subject choices. Students' behaviour and ability contribute to teachers' decision-making about type and/or length of practical work tasks. For younger students, when behaviour could not be assured, teachers tended to select demonstrations rather than "hands-on" activities.

Examination specifications

The change in England to a set of recommended practical experiments to be integrated into a programme of study from a specified piece of coursework taught and assessed separately, amounted to a significant change in teachers' practice. The study attempted to establish how teachers addressed this change. Qualitative data suggest the reform prompted some teachers to teach experiments that they had previously discounted as "too difficult" and/or "time-consuming" because they were now recommended in the practical work specifications. Teachers noted that integration of practical work within the GCSE and A level courses had improved and regarded this positively, noting an enhanced emphasis on individual research. Overall, changes to GCSE and A level qualifications in England acted as a positive factor, prompting teachers to introduce new practical work and reconsider experiments that they may have previously dismissed. There was no evidence that the amount of practical work offered to students had been reduced to the minimal number of experiments required in specifications. In Scotland, teachers commented that the introduction of assignments (detailed investigations) to the National 5 and Higher courses had led to increased rigour and upskilling of teachers (to act as external examiners) to ensure students are not disadvantaged within the practical work elements of their qualifications.

9.1.3 How does practical science contribute to preparing students for their next steps in science education?

When preparing the study, attention was given to students' trajectories in practical science, noting that these begin in primary school, continue through GCSEs (or equivalent) and, by choice, to post – 16. Transition points at 14, 16 and 18 represent up-lifts in cognitive and conceptual demand, with concomitant changes in practical work. We explored if teachers and heads of science believed their students were prepared to meet the needs of their next educational phase. Additionally, data were collected from staff involved with the teaching of first year undergraduate laboratory courses and first year science undergraduates. It is important to note that the sample of undergraduate students surveyed was small. Responses from undergraduate students have therefore only been used to provide a narrative insight into their experiences.

In schools, heads of science and science teachers in England in all age ranges considered students to be best prepared for following prepared instructions in their next phase. The school-university transition is significant as this represents the culmination of school-based practical work, leading into Higher Education. Data indicate that Higher Education staff's principal expectations of first year undergraduates are that they should be able to operate safely in a laboratory environment and follow and understand instructions. HE staff do not expect undergraduates to possess skills in specific scientific techniques. They note students' reliance on finding "the right answer". Given the high level of investment in practical work provision in terms of technical support, resource and facilities throughout secondary education this seems a surprisingly limited expectation. Implications arising from this are discussed later.

Data presented above show that beyond operating safely, HE staff believe that some basic skills are important for undergraduates to have in practical contexts. In summary, these are: the ability to use mathematical concepts and skills; note-taking; understanding theory behind scientific method; and the ability to solve problems independently. When these views are linked to data about the breadth of practical work offered in school, an emerging recommendation is that 11 – 18 year old students should be provided with a more balanced range of opportunities than the current strong emphasis on following instructions. Further, although working in pairs or groups at school has the benefit of developing collaborative working, there are indications that over-reliance on students carrying out practical work in pairs and groups in schools creates an inability to work independently once at university. Our data show that over 75% of post – 16 students in English state schools worked in pairs for at least half of the time when doing practical work; individual working almost never occurred in the 11 – 14 and 14 – 16 age ranges. Post – 16 students in independent schools experienced working individually more frequently than their state school counterparts. Failure to develop independent practical skills may impact students' confidence in university laboratories. We note that a small proportion of undergraduates reported practical activities in which they felt unable to do well because they lacked the necessary skills.

As the study progressed, although HE staff retained their general view that undergraduates were not well prepared for university study, they noted improvements in some aspects. These were: competence in scientific methods and practices, particularly planning experiments; and applying specialist methods and techniques when carrying out experiments or during field work. Biological science and chemistry HE staff found students better at solving problems independently, using mathematical concepts, and using specialist laboratory and/or fieldwork equipment. Biological sciences and physics HE staff reported improvements in students' competence in note-taking. However, it is important to note the small sample size from respondents teaching biological sciences. These are early findings post-reform, but suggest that integration of practical work and provision of a broad range of required experiments may be impacting positively on undergraduates' initial laboratory experiences at university.

9.2 Issues arising from responses to the research questions

9.2.1 Strengths and weaknesses in practical work provision

Several strengths are apparent in practical work provision in schools in England and Scotland. First, these data suggest consistency in terms of facilities, technical support and opportunities for students. This is a significant point, illustrating a degree of strength in the contribution that practical work makes to science as an academic discipline. There are indicators that support evidence reported elsewhere that students of all ages are motivated by science practical work. Here, we see that a significant proportion of practical work is hands-on and carried out within science lessons. Second, our data suggest team-working occurring between teachers and technicians in delivery of science practical work. Qualitative evidence suggests this engenders respect for the contribution that science technicians make to students' practical work experience, as they provide support and advice to teachers on a regular basis. In turn, teachers include technicians in curriculum discussions. The provision of science technicians in schools is a precious resource that should not be surrendered, as the range of practical work experiences made available to students relies heavily on their expertise. Third, although these data were collected at an early point in the reform cycle in England, indications are that the removal of the coursework components at GCSE and A level has not impacted detrimentally on resource made available for practical work. We report no significant changes in quantity, breadth, resourcing, or staffing. Teachers seem generally supportive of the move to required practical experiments, noting from the small number of science teachers participating in focus groups that this prompted positive changes to their pedagogical practice with similarly positive learning outcomes for students. This may, over time, point to improvements in preparation for science study in Higher Education.

Data also highlight weaknesses. First, the range of practical work opportunities is heavily reliant on following instructions. There may well be examination-based justifications for this position and there is evidence that pupils learn effectively when their enquiries are highly guided (Furtak, 2012; Lazonder, 2016). Nevertheless, this limits students' opportunities for developing conceptual understanding through other practical work experiences, as well as constraining their wider knowledge about scientific method, inquiry and practices. Lack of provision for long-term and extended experiments means students' perceptions of practical work are that experiments occur within a few moments and have (usually) pre-determined outcomes that are either "right" or "wrong". Although HE colleagues note improvements, application of mathematical concepts, understanding of scientific method and reducing reliance on obtaining "the right answer" are all aspects that engagement in practical work should deliver. The present reforms in England and Scotland may contribute to this over time. Second, expectations that school and HE staff have of practical work done in the previous phase of students' education seem limited. However, this is an expected consequence from a current system favouring practical work that promotes following instructions as a mainstay. When placed against the significant financial investment in running and servicing school laboratories, we should surely be expecting that students experience and know more. Third, a relatively small amount of time is devoted to field work and "outdoor" (or out of school) science of any kind. Applications of IT in school science are similarly limited. These aspects of practical work make resource and staffing demands, so may be judged difficult to deliver, and unnecessary if curricula specifications do not require this. We suggest that this means "school science" and the practical aspects of this become peculiarly limited to relatively small-scale, hands-on experiments.

10 Suggestions for future research

A number of issues of interest arise from this study. First, we are intrigued to understand in more detail how schools are in reality delivering a wide breadth of practical work to their students. We note some variation in the breadth and quantity of practical work being undertaken within our sample, but in the main, as a volunteer respondent group, a positive picture of the practical work being undertaken in schools emerges in a number of respects, as indicated above. The recent Gatsby (2017) study offers ten benchmarks which provide useful markers for high quality practical work in schools. Knowing more about how and if schools continue to meet these would be valuable. Second, variation in financial resource is noted. Knowing more about how funds are allocated to science and how these are spent would be useful. Third, the report has highlighted interesting differences between state and independent schools and further detailed investigation should be undertaken to identify possible reasons for these differences. Fourth, in terms of the examination reform, investigations of the impact these changes have on students would be worthwhile. These should probe students' attitudes and aspirations for science, and consider how participation in practical work impacts on these as well as on their conceptual understanding. A similar study of teachers' pedagogical practices related to practical work would provide insights likely to be valuable internationally. Finally, a similar set of data to that collected in this study should be gathered again in 2 – 3 years, once changes have embedded in schools and financial expenditure directly linked to provisioning for the reforms has stabilised.

11 Conclusion

This study presents data collected over a three-year period, commencing during the reforms to National 5 and Higher qualifications in Scotland and before the implementation of reforms to GCSE and A level science qualifications in England in May 2015, through to December 2017 when the first cohort of students completing the reformed A level qualification started undergraduate courses.

No substantial changes have yet been observed in the quantity or breath of practical work undertaken within schools in England and Scotland and practice in classroom appears to be relatively stable over time. However, changes due to the implementation of the new GCSE and A level specifications in England are ongoing and at the time of writing we expect schools to be in a period of flux. Therefore, findings presented in this report represent the picture within schools before and during the period of change only. Further research is required to assess the situation within schools in the post-reform era.

Expectations of Higher Education staff for undergraduates on arrival at university are currently limited, desiring only that students be able to operate safely within the laboratory environment and that they can follow and understand the instructions presented to them. HE staff do not consider it essential for students to arrive at university with skills in specific scientific techniques. However, we may hope that expectations might begin to change if early improvements that HE staff have noted in some aspects continue as the reforms in England and Scotland become embedded.

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