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GUIDE

Improving Statistical Skills through Students' Participation in the Development of Resources

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This paper summarises the evaluation of a project that involved undergraduate mathematics students in the development of teaching and learning resources for statistics modules taught in various departments of a university. This evaluation regards students' participation in the project and its impact on their learning of statistics, as characterised in terms of statistical reasoning, statistical thinking, and skills for statistical consultancy. The participation of students is evaluated from the viewpoint of communities of practice. The evaluation resulted in a characterisation of the benefits of such a project and suggestions for implementations of future projects, and in addition brought to light new theoretical elements both as regards the learning of statistics and as regards communities of practice. In particular, the analysis highlighted contributions of the students involved to resource development practice in the community of university statistics teachers, as well as contributions to students' learning as a result of participation in this community.

Keywords: Statistical thinking, statistical reasoning, statistics education, student internship, student dissertation, communities of practice, participation.

1. Introduction

Over the last three decades, statistics professionals have repeatedly expressed their concerns about the state of undergraduate education in statistics in the United States and the UK [1]. It seems that the number and quality of undergraduate programmes on statistics is insufficient to meet the high demand for qualified statisticians in business, economics and research. Over the past fifteen years, these concerns been acknowledged and curricular changes proposed towards improving of the quality of undergraduate statistical education (ibid). Additionally, the UK's national bodies have highlighted the need for improved quantitative skills in business and society ([2], [3]). In this spirit, councils, funding bodies and trusts have recently prioritised research in probability and statistics, especially as applied (see Engineering and Physical Sciences Research Council-EPSRC, [4]), and aim to strengthen quantitative methods teaching in social sciences (see Nuffield Foundation, [5]).

The developmental project we present in this paper aimed to address some of the aforementioned national and international priorities. This project takes place in a research-active university in the UK and its overall aim is the development of teaching, learning and research resources on quantitative methods through the cooperation of members of staff and students. So far, three students in their summer internships, eight students in their final year mathematics dissertation and six lecturers from four departments have been involved. The first author of the paper is a lecturer with expertise in mathematics education who offers one of the modules in statistics that benefit from the project. Additionally, she assists with the evaluation of the project from the educational research viewpoint. The second author is the

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primary supervisor of the project and offers the module that benefitted from the first phase of the project.

This paper draws on the literature to evaluate the students' experience of the design of these materials and the influence of the project on both the students and the practice of resource development. In this paper, we aim to respond to the following research questions:

(1) How did the students who participated evaluate the project?
(2) What meaning did students make of statistics and statistics education at the conclusion of the project?
(3) How and to what extent did students participate in a resource development practice during the project and how did this participation contribute to their learning?

The evaluation of the project from the viewpoint of the experience of and effect on staff participants, as well as an evaluation of the resources produced, will be carried out in future work.

2. Project Description and Outcomes

2.1. *The overall idea of the project*

The overall idea of this project, which has been through two phases so far, was to invite mathematics undergraduates who had attended a module in statistical modelling to create resources for statistics modules being taught in different departments across the university. During the first phase of the project, three students during a summer internship worked on developing resources for the module Statistical Methods in the Department of Mathematical Sciences. The internships were funded jointly by the National HE STEM Programme through the XXX project [6], and the Department of Mathematical Sciences. During the second phase of the project, eight final year dissertation students worked on modules taught by staff from four departments: Mathematical Sciences, the Mathematics Education Centre, Sport Science, and Information Science. The second phase of this project was funded by the Higher Education Academy through an individual teaching development grant.

The aims of the project were:

(1) To solidify interns' and dissertation students' understanding of statistical procedures and principles.
(2) To improve the interns' and dissertation students' understanding of how statistics is used in some other discipline.
(3) To give the intern and dissertation students transferrable skills, especially those relevant to consulting.
(4) To create effective final year dissertations for students that engage them in a real experience of curricular research in statistics and that motivate students through the knowledge that their work will be used by others.
(5) To learn what sorts of resources students are able to produce and are interested in working on, and what support they need to do this, in order to inform later phases of the project.
(6) To share ideas of statistical and educational best practice among students, members of staff in mathematics and members of staff in other disciplines.
(7) To support the lecturers teaching the modules by providing teaching resources.

(8) To improve the resources on statistics and quantitative methods available to students in the modules.

In this paper, we evaluate the project against the first five of these aims, which are the aims that relate to the interns and dissertation students.

2.2. *Description of modules, students and resources produced*

During the first phase of the project, resources were produced for the module Statistical Methods, which was a final year module for students in straight and joint honours degrees administered by the Department of Mathematical Sciences and taught by "Elizabeth". The aims of the module are the introduction of key statistical concepts such as significance, power, effect size, and statistical models and elements of design, as well as techniques of exploratory data analysis, statistical techniques for hypothesis testing and post-hoc testing in situations where the independent (predictor) variables are all categorical. Elizabeth is a lecturer in mathematics, with over 15 years' experience lecturing in that subject. However, she had no prior experience with statistics, either as a student or as a lecturer, before taking on the teaching of this module the year prior to the internship. Three interns, who had taken the module the previous autumn, were involved with the production of new resources: "Andy" and two others. Unfortunately, only Andy was available for interviews when the evaluation phase of this project began. The produced resources were the following:

(1) Six problem sets with solutions (created by interns not interviewed),
(2) four computer laboratory worksheets (labs) (created by Andy, MMath intern),
(3) four videos related to and expanding on the material in the labs (created by Andy), and
(4) a flowchart for deciding which of the various tests covered in the module to apply to a given set of data (created jointly by all interns and supervisor, Elizabeth).

In addition, one of the interns (not Andy) read through all of the lecture notes and commented on how to make the material more accessible to students, and the students worked together with Elizabeth to create a workable schedule for the module including deciding what material to cover in problem sets and what to cover in labs, and when those sessions should be scheduled in the term. Finally, the interns worked with Elizabeth to develop some sample courseworks and ideas for exam-type questions that would complement the resources being produced.

During the second phase of the project, resources were produced for five different modules by dissertation students. The students who invited to participate were straight honours students in their final years of either an MMath or a BSc Mathematics degree. All of these students had taken three previous modules in statistics: Introductory Probability and Statistics, Statistical Modelling and Statistical Methods. The BSc Mathematics students took Statistical Methods concurrently with the project during the first semester. The modules were chosen by contacting staff teaching statistics on campus via the university's Statistics and Quantitative Research teaching network, and asking if they would be interested in participating, and having resources developed for a module they taught. A member of staff from Sport Science ("David"), two members of staff from Information Science ("Roger" and "Dan"), and two members of staff from the Mathematics Education Centre ("Alicia" and "Mike") agreed to participate. The produced resources were the following:

(1) Statistical Modelling (aimed at second year students in mathematics, taught by Mike): a lab sheet and three videos on multiple linear regression in R, together with an assessment tool to evaluate the effectiveness of the video as compared to the lab sheet (created by "Beth", BSc)
(2) Statistics (aimed at second year students in engineering, taught by Alicia): two lab sheets–one on linear regression and correlation and one on t-tests and chi-squared tests (created by "Helen", BSc)
(3) Medical Statistics (aimed at third year students in mathematics, supervised by Elizabeth): a set of lecture notes on survival analysis, including explanations of how to run analyses in R (created by Andy) and a set of lecture notes on understanding and designing medical studies according to the European Medical Association protocol document including a real case study (created by "Frederick", BSc).
(4) Research Methods (aimed at second year students in information science, taught by Roger and Dan): five lab sheets leading students through a "research roadmap". There were worked examples for each lab sheet, and a set of Excel spreadsheets for carrying out the analyses in the final lab (all created jointly by "Carol" (BSc) and "Theresa" (MMath)).
(5) Quantitative Research (aimed at MSc students in sport science, taught by David): a sheet on simple linear regression, three videos on multiple linear regression in SPSS, a data sheet on handling missing data and imputation methods in SPSS (created by "Bridget", BSc), and a random data generating spreadsheet for logistic regression, a lab on binary logistic regression in SPSS, a lab on factorial anova in SPSS, and a lab on reliability testing in SPSS (created by "Victor", MMath).

3. Theoretical perspective

We use two theoretical lenses in the evaluation of the project. One regards students' learning, and is from the point of view of the goals of statistics education and the types of understanding that it aims to engender in students. The other regards students' participation in the project, and draws on the theoretical perspective of communities of practice.

3.1. *Goals of statistics education: statistical reasoning, statistical thinking, transferable skills*

There is no clear consensus on what is meant by statistical understanding. Even professional statisticians often debate the nature of their subject [7]. Statistics educators, moreover, hold a spectrum of views about the nature of statistics and what the goals of statistics education should be, which affect the message they transmit to their students [8]. According to Garfield and Ben-Zvi, [9], teaching design in statistics needs to take into account three distinct aspects of the discipline: *statistical literacy, statistical reasoning* and *statistical thinking*. Statistical literacy is "a key ability expected of citizens in information-laden societies." It involves "understanding and using the basic language and tools of statistics" that are necessary for everyday dealings with information (e.g. statistical symbols, representations of data etc.). Statistical reasoning is "the way people reason with statistical ideas and make sense of statistical information." It involves connecting concepts, combining ideas about data and chance, understanding statistical processes and interpreting statistical results [10]. Statistical thinking "is the way professional statisticians

think." [9]. It includes understanding "how and why to use a particular method, measure, design or statistical model; deep understanding of the theories underlying statistical processes and methods; as well as understanding the constraints and limitations of statistics and statistical inference" (ibid, p. 34). In Ben-Zvi and Garfield [11], statistical literacy is contrasted to statistical reasoning and statistical thinking as being "Thinking expected of adults in industrialised societies versus students learning statisics." For this reason, we will focus only on statistical reasoning and statistical thinking in the evaluation of this project. In our analysis, we draw in particular on the work of Pfannkuch and Wild in [12], and their five fundamental modes of statistical thinking: *recognition of the need for data*, *transnumeration*, *consideration of variation*, *reasoning with statistical models* and *integrating the statistical and contextual*. Also, we use the work of delMas in [13] to distinguish between statistical thinking and statistical reasoning.

In addition, it was anticipated that the project would develop useful transferable and employability skills. These skills concern a range of competencies such as: technical, managerial, communicational and consultancy that have been regarded as essential from prospective employers on training BSc statisticians [14]. Especially regarding consultancy skills, training needs to go further than the statistical knowledge as Belli [15] highlights. The skills considered by Belli include applied statistics problem solving, problem formulation, general problem solving, oral and written communication skills, interpersonal relations, ethical standards, session management and teaching within a consulting session. These perspectives from statistics education will be used to examine the second research question, which is related to the first three aims of the project.

3.2. *Communities of practice*

In our project, students worked closely with members of staff in resource development and engaged in activities which are not part of their usual university practices. In this sense, students found themselves taking on traditional staff roles as they became developers of learning resources. We see students' learning occurring in the social context of their interaction with staff and other students and in our evaluation, draw on the theoretical perspective of *communities of practice* as it was suggested by Wenger [16]. According to Wenger [16], *communities of practice* are formed by people who engage in a process of collective learning in a shared domain of human endeavour. In order to form a community of practice, people need to be involved in activities with the same objectives, share a concern or a passion for these and learn how to achieve them better as they interact regularly. The *practice* is the source of coherence for the *community*, and defines it through three dimensions: *mutual engagement*, *joint enterprise* and *shared repertoire* ([16], pp. 73-83). Several communities of practice relate to the teaching and learning of mathematics, especially at university level: undergraduate students, mathematicians and mathematics education researchers. These communities are characterised by particular practices and methods of communication, and they potentially interact with each other (e.g. [17], [18], [19]). Individuals make meaning in a community of practice through two key processes: *participation* and *reification*. Participation involves being within a community of practice, taking part in its activities, interacting and negotiating. Reification means "making into a thing...the process of giving form to our experience by producing objects that congeal this experience into thingness" ([16], p. 58). In these socially embedded processes, individuals learn by forming their identities of belonging (or not) in a community. There are three *modes of belonging*: *engagement*, *imagination* and *alignment* ([16], p. 173). Individuals who

engage with practice bring with them their own views and experiences (imagination) to weave a personal trajectory within the practice and they align with the norms and expectations of the practice. *Participation* is a source of identity; knowing what we *can* do forms what we are. At the same time, knowing what we *cannot* do forms what we are as well, so *non-participation* is also a source of identity. Non-participation is not necessarily a bad thing in identity formation in terms of the membership or not in the community. What is very important is the interaction between participation and non-participation and what dominates in this interaction.

In this study, we view university statistics teachers as a community that has teaching of statistics as a main practice. The mutual engagement includes teaching for statistical learning, learning of teaching of statistics and teaching design. The joint enterprise regards efficient teaching delivery (including assessment), development of effective resources that are effective, enhancement of students' learning experiences and teachers' professional development. The *shared repertoire* varies, and can include textbooks, software, online resources, symbols and discourses (technical, theoretical and pedagogical), as well as communication with colleagues and students.This practice is not stable, but is rather under a continuous negotiation between the teachers who are involved in this community and the overall institutional context in which this community is embedded. In principle, students do not belong to this community. However, in the context of the project presented in this paper, the participating students had the opportunity to engage with practices of the community of teachers–at least with some of these practices–and bring to the community their own experiences and knowledge (their imagination). Through the mutual engagement of students and members of staff a new *boundary practice* is emerging, the practice of resource development. This practice has the potential to perturb the rules of the community of university statistics teachers on the one hand, and changes students' identities on the other. We investigate this hypothesis in our third research question, which relates to the fourth and fifth aims of the project.

4. Evaluation Methodology

4.1. *Data Collection*

Our overall goals for evaluating the project were to assess firstly the quality and effectiveness of the resources produced, and secondly, the impact on the interns and dissertation students who were involved in the production of these resources. In this paper we report outcomes only from the latter and present results from the analysis of the following data set:

- Semi structured interview with Andy after his internship.
- Five dissertation students' anonymous written responses to a questionnaire at an interim stage of their dissertation at the end of the first term.
- All dissertation students' feedback after the completion of their dissertations. Due to restrictions on students' availability the feedback was collected in the following forms:
  - Semi structured interviews with two groups of three (Frederick, Beth, Helen) and two students (Victor, Bridget).
  - Semi structured interview with Andy.
  - Written responses from the remaining two dissertation students (Carol, Theressa) to the questionnaire on which the interviews above were based.
- Final outcomes from students' dissertations, including the resources produced.

The audiotaped interviews were conducted by post graduate students who were not involved with the project, and transcribed by third parties. The list of questions asked in the interviews and the questionnaires were developed by the authors in accordance with the eight aims of the project presented earlier (see a sample of these questions in Appendix A). Institutional ethics approval was sought and obtained for these interviews, and all participants signed informed consent forms indicating how the resulting data would be used.

4.2. *Analysis*

We analysed the interview transcripts and students' responses according to our research questions with references to the final outcomes from students' dissertations. Several iterations of coding and categorising by each one of us individually and together in consultation and interaction with existing literature in this area refined our theoretical perspective as well as the research questions. The first research question: "How did the students who participated evaluate the project?" was refined to:

(1) what did students enjoy most about the project?
(2) how do they describe their support from and interactions with staff during the project?
(3) what challenges did they face?
(4) what recommendations would they suggest for future implementations of similar projects?

The second research question: "What meaning did students make of statistics and statistics education at the conclusion of the project?" was refined in order to include specific aspects of this meaning in relation to statistical thinking and reasoning and transferrable skills. In this sense the second question was refined to:

(1) How well were students able to demonstrate statistical thinking and statistical reasoning after the conclusion of the two phases?
(2) How well were students able to demonstrate transferrable skills after the conclusion of the two phases?

For statistical thinking we looked for evidences regarding the five modes of statistical thinking proposed by Pfannkuch and Wild in [12]; for statistical reasoning we looked for evidence of relating underlying theory to practice, following the distinction made by delMas [13]; for transferrable skills we looked for evidences of any of the skills considered by Belli [15] required for statistical consulting.

The third research question: "How and to what extent did students participate in a resource development practice during the project and how did this participation contribute to their learning?" was refined to:

(1) What was the role, if any, of students' participation in resource development in their learning?
(2) Did student participants experience a double identity of student and resource developer, and if so, how did they deal with it?
(3) What contribution, if any, did students' double identities make to the practice of resource developers?

All the above aspects were analysed from the students' perspective as evidenced in their feedback (interviews/questionnaire). For the contribution of participation in students learning, we looked for evidence in which students speak about how their understanding of statistical concepts was affected by their role as resource

developers. Regarding if students experienced a double identity, we looked for evidence in which students' perspectives shift between their roles as students and as developers. Specifically, we were interested in identifying points in which participants spoke either with the identity of the developer or with that of a student, or even mixed these two identities, in their utterances about their engagement in the project. Regarding students' contribution to the practice of resource developers, we were looking for points in which students described their contribution to the existing practice.

5. Results from the viewpoint of statistics education

5.1. *How the students who participated evaluated the project*

5.1.1. Students' enjoyment of the project

In interviews and written comments, all students commented about their enjoyment of the project. Helen commented, "I think...they could do with more projects...around this area."[1] In answer to the question "What do you think has been best about this project?" six students (Andy, Beth, Frederick, Victor, Andy and Carol) mentioned the fact that their work would be used. Andy said, "I think one of the big things is that it's going to be used. It's not just you've done a project and then it's gonna sit in a pile forever and never be seen again. It's actually going to be used by other people." Carol and Bridget mentioned the group work aspect of the project. Helen said she liked learning about education, as she intends to become a teacher. Victor further commented on his enjoyment: "I've really got into it and it's made it quite easy to do it, 'cause it's been enjoyable. It hasn't seemed like a lot of work. When we finally got around to writing up our reports, we realised how much work we had actually done for that year, and it was...quite a shock."

Throughout the rest of the interviews, various additional comments were made about working in a group of students. It seems that students had different views about what aspect of group work they found most useful. Some students liked being part of a large group all working on similar dissertations. Bridget said, "I've liked the fact that this has been loads of people to talk about things. We had lots of meetings and discussed different things. That's made it...more enjoyable, I think." Beth felt that some additional meetings with other students would have been helpful when learning new tools, in particular, Camtasia, which was used to produce screencasts. By contrast, at least one student, Andy, found the small groups helpful, but was not as interested in the large groups:

> I didn't really want to sit there for forty-five minutes and listen to other people's dissertations. Especially when there's eight people...I didn't find them as useful. But the individual stuff or even...pairing off. Sometimes I met with one other person and Elizabeth, and they were useful because it's good to get a student's perspective on things as well.

5.1.2. Support from and interactions with staff

All of the dissertation students felt that they had been well-supported in the second phase of the project, and Andy additionally felt he had been well-supported during the internship phase. He described the support during the internship phase as follows:

[1]In quotations from students responses, ellipses are used to eliminate verbal tics (such as "um" or "like" or "kind of") and thereby improve readability.

> That always got feedback straight away. The feedback we had set for it from Elizabeth was saying, 'this is good, but you need to change blah...' I would go away and change it, show it to her again, and then maybe a couple more things needed changing. But they were good. I didn't get as much feedback on the lab sheets, but that was because Elizabeth hadn't really done R at that point, so we couldn't really do much. I got feedback off one of the PhD. students, so that was useful. So, there was loads of feedback when we were doing the actual thing. And I did really enjoy the internship. I found it really useful.

He added that an important factor was that, "Elizabeth is great in terms of making you feel welcome." During the second phase, Andy again described his meetings as useful, "I found individual meetings with Elizabeth really useful. Where if I was stuck and we could just sit down there for an hour and go through it together." It is interesting to note that in the second phase of the project, Andy's description of his interactions with Elizabeth puts them closer to collaborations of equals rather than direction from a supervisor: "like Elizabeth, we were both learning it as we'd go along. She knew no more than I did, and I knew no more than she did."

Frederick also found the working relationship to be collaborative.

> Communication was two way. Like Elizabeth gave me the opportunity to do what I wanted, and then if she found something that was just completely wrong or she didn't quite like the idea of, we'd talk about it and then go on from there.

Other students in the second phase also felt that the support from and collaboration with staff was good. Victor described his meetings with Bridget, Elizabeth and David as follows:

> I think we had...very successful meetings... We met a member of staff at least once a week, either David or Elizabeth. That, that was helpful. And then we spoke to each other quite a lot about what we were doing and different ideas for each other, and how things could be improved.

Bridget echoed this, "we got...quite good guidance from both David and Elizabeth as to how...the problem sheet should be structured and what they wanted from resources." However, sometimes Bridget felt that the meetings did not cover what they needed to: "I think it was particularly useful to see David fairly often, although there was a lot of times where...he'd get talking about something and then that was the whole meeting gone without really looking at resources."

Helen and Beth's descriptions of the support they received was more like support from an advisor, and less collaborative. Helen described her support from Alicia as follows: "I worked closely with Alicia, and so she was always aware of what was going into the problem sheets and whether it was suitable or not." She summarised the support as an important balance to the difficulty of the project: "It's been more challenging than I first expected but at the same time the support has been great." Beth reported, "I think I worked quite a lot with staff, like I met with Mike and Elizabeth a lot," and "Elizabeth and Mike checked through everything I that I created." Overall, she said about the support she received, "I can't really think of anywhere where it could be improved."

5.1.3. Challenges students faced

Difficulties mentioned by students include those related to educational practice. The most commonly mentioned difficulty was time constraints. Beth commented:

> I think time became a bit of an issue at the end, because we...realised I had to suddenly do them, I think it was about week 6 and we wanted to get them done before Easter, I kind of had about a week to...get everything produced and finalized.

Helen felt that time constraints limited the quality of resources she was able to produce:

> I'd say, time constraints because we wanted the resource to be used this year and we had to make them...sometimes I had three weeks to make a problem sheet or the others, I had just one week to make a problem sheet, so...I'd just say if I'd had a bit more time it would have been better.

She also mentioned the issue of time constraints in determining how students in the module for engineers would use the materials:

> I wanted to find out more about how statistics was actually used in all of the courses that the students were on from the department of materials in engineering. But with the time constraints and everything, they didn't reply to our emails in time so we just went ahead and made the problem sheet without that information.

Finally, some students mentioned they would have liked to observe how the resources were used, and to discuss with the students using them, but that there was not the time to do this.

Another difficulty, mentioned particularly by the students working on resources for students not in mathematics, was dealing with making the material accessible to the range of students on the module. Carol wrote, "I learned that statistics is taught carefully in this module as only 15% of the students have A-level maths and as a result they are wary when it comes to learning statistics." Victor made similar comments about tailoring resources to the students in the sport science module.

Finally, many of the students felt that they did not know at the beginning of the project what they were supposed to be doing. A characteristic comment was from Bridget: "I do feel like it took a long time to kind of get the ball rolling and actually get started on work." Some students, such as Carol, attributed this to the novelty of the dissertations, "At the beginning I was very confused about what was going on and what I was expected to be doing. I think this was just because this type of project was new to everyone." Several students made comments on their expectations for improvements in future such dissertations. For instance, Frederick said:

> I think we all succeeded in creating a foundation for future projects and now that we know what our projects were about in the end, I think students who take over from us, if they do, they'll be more clear on what their project will be from the start.

5.1.4. Students suggestions for future implementation of similar projects

Students also had some suggestions for how the dissertations could be improved in the future, which reflected the difficulties they mentioned. These included having a clearer plan at the start of the dissertation and getting more chances to get feedback on their resources from students who used them. One student, Victor, suggested getting a sense of the students at the start of the dissertation:

> I think it would be a good idea if maybe right at the start of the project, we went in and spent just a little bit of time with them, because they will have lab sessions so we could go in and...sit in a lab session, see how...the students work. It would just give you a better idea of what you were looking at.

5.2. *Students' demonstrations of statistical thinking after the conclusion of the project*

The interviews and questionnaires show evidence of various modes of thought relevant to statistical thinking [12]. Furthermore, our analysis revealed a sixth mode of thought, which we call *awareness of multiple approaches*, which we also discuss.

5.2.1. Recognition of the need for data

Understandably, students whose projects related to modules focused on design, namely, the information science and clinical trial protocols projects, had several quotes relevant to this area. For instance, Frederick commented on design for medical trials, "You can't just do [a medical trial]. You've gotta go through about a year's practice and development. 'Cause obviously, it's a serious matter. You can't just come up with an idea and test it." Both students working with information science mentioned the importance of design. Carol recognised, "Everything they study comes back to how well the survey was designed in the first place." Teresa commented, "There are so many points that need to be considered when designing a survey; there is much more effort needed than people think." Additionally, Beth designed a study herself, and said she learned from that how to create a protocol and design a study.

5.2.2. Transnumeration

Transnumeration is related to the exploratory stage of data analysis, in which summary statistics are calculated and uni, bi and multivariate graphical methods are used to look for patterns and anomalies in data. In the first phase of the project (the internships), one of the videos and labs produced by Andy involved exploratory analysis for two-way ANOVA. In the second phase, the lecure notes Andy produced on survival analysis, the videos Beth produced for statistical modelling, the videos Bridget produced and labs she and Victor produced for the sports statistics module and the labs Helen produced for the engineering module all involved material about exploratory analysis. After his internship, Andy mentioned one new type of plot he had seen, and how that can be used to understand data in a new way:

> I had never come across interaction plots before. They were quite nice in seeing if the two separate variables depended on one another and then calculating it. And then, from that you can sort of see, 'Oh, we're likely to have some sort of interaction here.'

Victor mentioned the lack of exploratory analysis in the existing materials for the module he was working on, "The resources he had...there wasn't a lot of preliminary analysis, and it didn't include a lot of graphs and things that could help...explain later. So, that we added quite a lot of that in." Beth, whose dissertation involved writing and marking a formative assessment for her study, noticed that the ability to use plots to study data was a weakness among the students in her module, "Working on this project, it became quite apparent that students...didn't have the basic statistical understanding of...exploratory analysis."

5.2.3. Consideration of variation

There was less evidence in the interviews of the consideration of variation. This topic was, however, closely related to the development of resources on designing a statistical protocol for a medical trial. Frederick said in his interview:

> In Stats Modeling and Stats Methods, we learned a couple of designs, but in this there were many more, and so the main thing was much greater range of statistics and design that we used, and you have to be very careful about when to apply each one.

The report he wrote included a variety of topics relevant to the control of variation in experimental design. These included: nuisance variables and stratification, the placebo effect, observer-blind, subject-blind and double-blind trials, inclusion and exclusion criteria, screening, and the difference between full data sets and per-protocol sets.

5.2.4. Reasoning with models

Quite a lot of the work the students undertook involved reasoning with models. One part of this was understanding how to decide what model and what sort of test to apply to data. Andy mentioned this as one of the main things he learned from his internship: "Picking what test to use–that was quite a big one, in terms of what sort of variables were we dealing with and what variables weren't we dealing with." Again, Beth saw this as a weakness among the students in the module she was working on: "they...didn't really know that it was useful to classify their variables...'cause that means they have to carry out different tests." Carol and Teresa had the additional difficulty of choosing a small set of tests for the often math-phobic students in Information Science to learn that would cover at least some of the questions they might want to answer. Carol says, "I used some of my knowledge from the module Statistical Methods and the recommended textbook...to work out which statistical tests would be best for the students to use on particular data sets."

Another aspect of reasoning with models came up when students used Excel to create realistic random data according to various statistical models. Four of the students did this in the second phase of the project–Andy, Helen, Bridget and Victor. Bridget and Victor discussed this in their group interview. Bridget found this part one of the most challenging in her dissertation: "I found it really difficult to find an example that was going to work, and to create data that backed up the example that showed the things I wanted to show." Victor enjoyed the challenge of creating questions and data:

> I quite enjoyed coming up with the...actual research questions and then creating the data around that because we had to create our own data–to do a little bit of research into what sort of questions would fit in with each of the different tests and whether they'd give us...good enough results that could mean something to the students.

Both students were eventually able to create datasets using Excel and summary statistics from studies in the sport science literature to create meaningful datasets for sport science that also demonstrated the relevant inference procedures.

5.2.5. Integrating the context

One aim of setting dissertations within modules in different departments was to give the project students a sense of how the context influenced the implementation of statistical analysis. Beth commented the benefit to her of seeing how statistics was used in sport science: "Normally we...use stats in kind of almost an abstract way. This was more examples, to see how it fits into...real life." Victor tried to create resources to encourage the sport science students to integrate the context when drawing conclusions: "What we were trying to teach them was to take their numerical conclusions and apply them within a whole discipline, sort of using areas from the whole subject to make...conclusions about that certain research." Beth felt that more integration of context would be useful in her module for maths students, and said, "I think they just learnt it as more of a predictive model, but there weren't necessarily many examples about when you would use it in...real life situations."

5.2.6. Awareness of multiple approaches

An aspect that we believe is involved in statistical thinking, but which is not enumerated in the Pfannkuch's and Wild's list of five modes, relates to the awareness of multiple possible valid approaches to analysis of a given dataset. For instance, two statisticians may chose different graphical methods to explore a dataset and elucidate their findings, or may choose to treat a given dataset through parametric

or nonparametric methods. Two students made comments related to this in their interviews. Frederick mentioned this as one of the main difficulties in statistics, perhaps especially for mathematics students, who are accustomed to single correct answers:

> Unfortunately, statistics isn't as clear as...there's not an algorithm as such that you can just go through. Like, you can make one, which is the aim of [the flowchart] but it's not like black and white because...there's little bits and each one, like variables, can go in two directions in certain things.

Andy also mentioned that this could make people uncomfortable:

> Say if you're doing exploratory analysis for something, there are hundreds of ways you can go about it. And I think people get worried that because their way isn't the same way as the person next to them, that they've done it wrong and they haven't.

5.3. *Students' demonstrations of statistical reasoning after the conclusion of the project*

Whereas statistical thinking relates to understanding the process of analysing data, we have taken from the work of delMas a characterisation of statistical reasoning involving relating underlying theory about statistics to the ways in which tests are implemented or interpreted [13]. Andy mentioned this as one of the places his understanding had improved through the internship.

> My understanding improved in...how you interpret your results and what this means. For example, a p-value of 0.05 means that there's a one in 20 chance that you drew that sample at random and things like that. Before, it was just that if p is less than 0.05, then it's significant, and if it's not, then it isn't.

Although his definition of p-value is not quite precise, he has clearly understood that it has a precise definition, and perhaps in a more formal context could have produced the correct one.

Most of the students touched to a lesser or greater degree on the relationship between statistics theory and practice in their dissertations, and included sections of theory expanding on the material that was covered in the resources they produced. In the group interviews, students commented on the failure of the pre-existing resources in the modules they were working on to unify theory and implementation. Victor explained why this is a problem,

> They're taught to the students so that they can learn how to implement the tests. They don't actually get into learning really about the statistics. They learn a step-by-step guide of how to use the test and what the test means. So it could be difficult for them...when they come to use the test in different areas. If they've got to make alterations, they wouldn't know how to do that...they'd need to learn more about the underlying stats than the actual test itself.

Students also discussed how they tried to improve this aspect of the resources. Sometimes, this was done by including more information: "Our lab sheets included information on population and sample size and a lot of information about hypotheses, interpreting p-values and statistical tests." Helen felt she improved her resources simply by including questions: "The resources I created actually asked questions to the students, which the old ones didn't, so they were actually having to think about the statistics they were using and try to understand why."

5.4. *Evidence of transferable and consulting skills*

All of the students undertook tasks in their dissertations that required transferrable skills important in consulting. In particular, all eight students in the second phase of the project wrote dissertations about their work, which developed written communication skills. In his second interview, Andy articulated the value of the transferrable skills training: "It almost gives you a new skill set." When asked to elaborate, he mentioned grammar, structuring a report and other writing skills, as well as organising work and working to deadlines. Similar skills were mentioned by other students, as well. Students working on dissertations for information science and sport science needed to learn to run effective meetings (session management) and communicate with people from various backgrounds (communication). Carol wrote, "Meetings improved throughout the year as we were getting to grips with the aims," and Theresa said, "Every meeting there was good communications between staff and students. Any issues either party had was always raised and usually sorted in the meetings." By contrast, Bridget and Victor sometimes found it was difficult to get around to everything in meetings that was necessary, especially given the amount of time that the module lecturer was able to spend discussing with them.

Students also needed to learn how much and what teaching to do within their consulting role (teaching in a consulting session). Students commented particularly on the need to balance their views on how things should be done with the opinions and needs of the staff teaching and students taking the modules for which the resources were developed. For instance, the two students working on the Quantitative Methods module in sport science discussed working within the formats of existing materials for the module. Victor said, "[What I liked least was] formatting the questions so that they would then fit in with the way he wanted it done. I think maybe there would have been better ways to do it." Bridget added to this:

> There were things that we wanted to change [but] we wanted to kind of keep the structure he already had so we had to make sure we weren't kind of going out of our way to change everything.

Theresa, working with the module Research Methods in Information Science, mentioned a similar challenge relating to convincing the module lectures, for whom they were effectively consulting, to do things in new ways:

> I learnt that staff in the information science department seemed to be quite strong minded, in that they didn't want to make many changes. However, we did manage to make some small changes by providing a convincing argument.

We will return to this comment in the next section.

There were also aspects of consulting that the students needed to learn to deal with, but which they did not seem to recognise as normal parts of consulting projects. For instance, the comments mentioned earlier about time constraints relate to learning to work within a particular time frame for a project, which relates to general project management. The comments about not knowing at first what they were supposed to do also show that the students have had an experience of the first part of consulting, problem formation. The negotiations with members of staff in Sport Science and Information Science relate, among other things, to interpersonal skills.

6. Results from the viewpoint of communities of practice

6.1. *Students' learning through their participation in resource development*

Our analysis of the data from the viewpoint of communities of practice indicated six characteristics of this practice that students valued as important in their learning of statistics.

The first characteristic is related to the *responsibility for future students' learning*, which participating students felt. This led them towards the creation of accurate materials that would be clear to other students. Beth, for example, mentioned that she would seek assistance from her supervisors to "double check before...including it [an item] in a resource and then confusing the student." They claimed that their participation in the resource development supported the solidification of their knowledge in order to be able to teach it. Andy, for example, in a question on what he learnt from his involvement in the internship (first phase) mentioned: "When you're making these resources you have to have a good understanding because if you don't understand you're never going to be able to make someone else understand," and later he added, "I thought I knew quite a lot of that sort of stuff before hand, but it just sort of solidified my knowledge, really." Also, he acknowledged how this engagement helped him to give a structure to his thoughts:

> When you have to go through each chapter step by step and we're reorganising it you have to know...what follows on from what. And just...the organisation of my thoughts really...I knew bits and bobs but I...couldn't take someone through the problem. [If] someone asked me, 'How do you do this?' I might have known, but then I might not have known what to do next.

Victor mentioned explicitly that he had to learn himself firstly, before being able to help somebody else's learning:

> Along with research design...I was trying to help the students learn how to...design research, so I...learned a few little things to try and then teach them about...samples sizes.

The second characteristic concerned the *usefulness of the outcome* of the overall endeavour; as Frederick mentioned "the resources we created will actually be used, and I think that was the biggest motivation."

The third characteristic, related also to the previous one, was the *demand of ideas that will motivate* those who will use the produced resources. Participating students had to broaden their views and to work hard in order to find these motivating ideas. Victor, for example, mentioned that he had:

> to do a little bit of research into what sort of questions would fit in with each of the different tests and whether they'd give us...results that..., could mean something to the students, that they could really follow and analyze properly.

Motivating ideas are also related to the fourth characteristic concerning the creation of resources by *modelling real and relevant experiments*. In those cases students had to create examples based on learning scenarios inspired by and of relevance to other than mathematics disciplines (e.g. engineering or sports science) which were novel to the participating students. Bridget, for example, mentioned that she:

> found it quite interesting to see how it [statistics] applied to a different discipline. Cause normally we...use stats in...almost an abstract way. This was just more examples, to see how it fits into...real life, and how they use it in their modules.

The fifth characteristic is related to the need of *awareness of alternative vocab-*

ulary from other disciplines. Victor and Bridget, who were engaged with statistics for Sports and Exercise students, dealt with the variation of the uses of statistical terminology and how the disciplinary context changes the statistical discourse. Similarly Theresa, who developed resources for Information Science students, noticed that: "From group meetings with the other students it was very clear different modules and courses use different terminology to mean the same thing."

Finally, the sixth characteristic is related to students *involvement in statistical teaching* and its contribution to their understanding of how statistics is taught or learnt. Helen, for example, who dedicated a substantial part of her dissertation in statistics education literature in order to develop lab resources for a module in statistics for engineers, was very clear:

> I didn't learn much new around statistics. I learned more about how statistics is learned and how it is taught and more about the... teaching techniques around statistics, because there's lots of...common misconceptions when students are learning statistics. I learned more about how to deal with their misconceptions rather than more about statistics. I learned more about education.

Beth, "through working on this project" learnt about other students' understanding: "it became quite apparent that students...didn't have the basic statistical understanding...of...exploratory analysis." Furthermore, from the assessment perspective, Victor who worked with the module lecture in the development of assessment materials,

> [...] learned a lot about the way they like to...set up problem sheets, so that it really works through'..I don't think you really notice it when you're doing it yourself, because it's just there for you but, both members of staff like to set out problem sheets in a certain way so they really help the students go all the way through the test, instead of working on just little bits. So...if you don't work on them, and set up one yourself, you don't really understand that, because you just sort of take it for granted that it's there.

6.2. *Students' multiple identities*

The students who were involved in this project brought their experiences (as learners who had attended statistical modules in the course of their mathematics degree) into a practice of resource development that is usually allocated to their teachers. We can say that we have two different perspectives here connected to different possible identities: the identity of a student and the identity of a resource developer. There were various ways in which the participants interacted with these perspectives. In some cases, the participants took on one or the other perspective. Helen spoke explicitly on how she saw herself on the other side of the *wall*: "I think it was really interesting to be at the other end of the...lab sheets. ...Usually we're the ones that have been doing the lab sheets and now we're the ones creating them." In the same spirit, Bridget realised that "[she] never really thought about it [statistics and education] before, so it was nice to look at the other side of it as well." There were cases in which participating students took clearly the students' perspective and stood critically against lecturers' practices. Helen, for example, although in other points she said that she had found herself "at the other end" she distinguished herself from what lecturers have been doing:

> I don't think lecturers are always aware of how...difficult it is to learn a new module from scratch, so that when everything's taught to you...in lectures, students don't always make the link between, between lectures or between labs and lectures.

However, there are cases in which being "at the other end" made them to view a lecturer's work with sympathy. Andy, for example, in the first phase of the project developed resources for a new module which had some fluctuations in the quality of its delivery the year after (at the time the interview was taken). He clearly distanced himself and the resources he had created from the lecture delivery in his critique: "They [current students] feel like Elizabeth is a bit all over the place with how she's delivering the module. So, I don't think the resources are the problem; it might be more the delivery." However, later he commented with sympathy on the lecturer's effort: "[u]nless it's slightly down to the fact that it is all new content, so it's going to be all over the place in the first year of giving it."

Often participating students mixed up the student's and the developer's perspectives in the same utterance, as the following excerpt from Frederick indicates:

> Statistics has no simple aspects. I would say...very complicated ones at the same time. And they've all gotta be linked. 'Cause students...I quite liked statistics when I was at school and stuff, but when we did all these modules, I was so confused. It was only when I redid this that I understood stuff that I never understood in Stats Modelling and Stats Methods. I just wrote answers that I learned, but that didn't mean I understood them; it just meant I could memorise them.

In this excerpt Frederick starts speaking as developer about statistics and what students do and he shifts to what he used to do as a student. Based on examples such as this, we believe it is inappropriate to talk about a distinction between the students' and the developers' *identities*, as these two were not clearly separated from the evidence of participant students' responses. We prefer to speak about different *perspectives* and shifts between these perspectives.

Another interesting observation is how participants, who had to develop resources for non-mathematics students and collaborate with a lecturer who was not mathematician or statistician, saw themselves as *mathematicians* in juxtaposition to those who were not. Victor, one of these participants, distanced himself from the position of the students to whom the materials he was preparing were targeted:

> I think really...making...the questioning...straightforward enough so that the students could understand, as well as really sort of helping them learn how to use the tests, each time. ...Trying to balance what we know...from maths as well and trying to tailor that towards these students. That was...a quite difficult thing, because we'd not come from that background, so we didn't really know what they expected from it.

This was not the case with the participants who were preparing materials for modules they had attended in the past as we will see in more details in the next section.

6.3. *Students' contribution to the resource development practice*

From students' responses, we can identify a range of aspects in the resource development practice to which they had the opportunity to contribute. The first aspect relates to the fact that a student as a learner and as a developer at the same time can *bring more insight* into how students - the final users of these resources - obtain the statistical knowledge, as Frederick mentions:

> So, if I was a student, I'd have...got stuck at the same points I got stuck at when I was trying to produce the notes. So, it's basically I learned that when the lecturers, like Elizabeth, she might understand something...but when they're producing it you have to be able to produce it within the student's knowledge, or what they've already learned from before. So I've probably learned that having a student create

> the resources meant that...it should be to the level which is understandable for the new student.

According to Andy, the above is not necessarily important if the lecturer has already the necessary pedagogical knowledge and sensitivity to students' needs - as it proved true for the lecturers who contributed to his dissertation. However, he felt this was not always the case: "with some lecturers I was more critical of and I maybe I could have given them an insight [laughs]. But I feel like Mike and Elizabeth...if anything, they gave me an insight into students."

A second aspect is the *internal knowledge* students bring in the resource development. This aspect was applicable to those students who developed materials for a module they had attended recently and were able to bring in their experience as learners. As Frederick says:

> I think it's right that we can give back...to the other students that are in the years below us, because when we took the modules ourselves, we knew exactly what the strengths and weaknesses of the module, so if we use our knowledge for that, to actually carry out a dissertation, that benefits us and also...the students following on from us, I think that's a really a good idea.

A third aspect relates to the *new techniques* students can bring in the evaluation of the new resources. Frederick for example, piloted the new materials with his peers: "I had people in my house and also people on the course, who were...doing the same process, reading through it to make sure that they understood it or were able to understand most of it". For future similar dissertations, he also suggested testing the materials with students who are at the same position as the students who will attend the module:

> Yeah, it's just important to listen to other people who have taken the previous module...who...would have the same knowledge as a student going into this module, to see if they were able to understand and find the notes useful.

Beth ran a small test and survey to evaluate how the new resources were perceived by the students, and brought to Mike's attention some student difficulties of which he was not aware:

> ...because [Mike's] students get good marks, I don't think he really realised that they don't have the basic understanding that you would need to...carry out their own statistical analysis. I think that has definitely brought it to his attention, that he needs to focus more on...the initial stages a bit, which...was a useful thing.

6.4. *Students' participation in the community of university statistics teachers*

A key concept in communities of practice is participation. Our analysis of the data revealed that there were varying levels to which the project students participated in the community of resource developers. These differences seemed to relate to the challenges students faced in their projects and to the ways in which they dealt with these challenges. Some of them dealt with difficulties through hard work, seeking help from their supervisors and other members of staff, searching the available resources, expanding their skills (e.g. learning a new software), and negotiating with other students and members of staff. One of these students was Beth, who claimed:

> [...] having the meetings with Mike and Elizabeth I never really felt I had to create things on my own. I..talked through...video scripts to make sure to fit in with...the way that Mike's module would be run, and...having Elizabeth check them for...terminology

> to make sure that all things I said about statistics were correct. So I think it was good communications there because I felt like I could like voice my own opinion...they weren't...just telling me what to do - it was...a teamwork effort, rather than they were just instructing me how to do it...I was allowed the independence to run with it on my own and then just double check with them that it was okay.

Beth chose to *participate* in the practice and gradually gain the ownership of what she were doing. This was not the case with other students who, although working hard under the guidance of their supervisors, did not always have this sense of ownership. Helen, for example, in her retrospective reflection admitted:

> [There was] one particular case where...we were talking about questions that would...go on a problem sheet...I didn't really say anything, but one of the questions seemed very ambiguous, and even I didn't really understand the wording of it,...although...I understood what the lecturers...wanted to achieve from the question. I think as a student I already knew that it was going to be quite difficult for students to understand, even though it was quite straightforward. I think I could probably have enlightened them on that a bit more, given my personal opinion on wording of questions.

Helen, at least in this excerpt, took a distance from her supervisors' position and, although she disagreed, she did not feel legitimate enough to express her opinion and she chose to *not participate*.

Helen, Theresa, Carol, Bridget and Victor, who worked for non-mathematics modules, faced a particular challenge in working with staff and/or students from subjects other than mathematics. They all made comments related to difficulties understanding the context of a module they did not know. As Bridget said:

> I think it would almost have been nicer to just be more involved in the actual module...because it felt a bit like we're doing all this work for it, but I don't actually know that much about this module–how it's taught, what the lectures are like, what the labs are like.

There were also some tensions between students' expectations based on their experiences in mathematics, and module lecturers' practices in other disciplines. Carol, for example, would "like to have all resources available on LEARN [university's VLE]," whereas the module lecturer "was very reserved about putting things on LEARN as he felt it would reduce the number of students that attended the timetabled lab sessions." Furthermore, the negotiation between a mathematics students who had the *statistical education* perspective, and a desire to introduce *more or different content* to the resources, and a lecturer who wanted to retain his practices is evident in the following excerpt from Victor:

> We were looking at the statistical education...the different...aims of that...as well as trying to add more mathematical content to it, so that...was sort of our aims for the resources. And I think [David's] aims were just to allow the students to understand it and implement the test. So we were trying to balance the two set of aims to really allow them to understand it in the way that he has been already, but then adding...more content, so they could understand it better. And that was...where a lot of the discussion lay, as to where the...crossover line was.

The mathematical content was also an issue for the two students working with the Information Science module. Theresa mentioned "staff in the Information Science department seemed to be quite strong minded, in that they didn't want to make many changes. However, we did manage to make some small changes by providing a convincing argument." Summarising the above observations, we would say that Helen, Theresa, Carol, Bridget and Victor sometimes found themselves at a distance from the practice and *not fully participating*.

7. Conclusions

7.1. *Evaluation of the project: Students' learning and participation*

In the evaluation of a project in which students cooperated with members of staff in the development of resources, apart from looking for evidence of students' learning, we tried to make a connection between this learning and students' participation in a resource development practice. This investigation revealed that students explicitly linked their participation to the solidification and organisation of their statistical knowledge. This statistical knowledge was evident in the terms of statistical thinking [12] and reasoning [13] as well as consultancy skills [15]. Furthermore, this participation contributed to their learning about how statistics is taught and learnt and, especially for non-mathematics students to their learning of the statistical discourse and its contextual variations. Our analysis indicated six characteristics of resource development practices that students valued as important in their learning of statistics: responsibility for future students learning, usefulness of the outcome, demand of ideas that will motivate, modelling real and relevant experiments, awareness of alternative vocabulary and involvement in statistical teaching.

We analysed students' responses in relation to the perspectives of student and resource developer. Our analysis revealed that students interwove both perspectives in their responses, sometimes speaking as students and sometimes speaking as developers. Moreover, there were cases in which students intuitively used both perspectives in the same utterance. Additionally, students who worked on materials for non-mathematics departments demonstrated their *mathematical* identity in juxtaposition with the non-mathematical expertise of the targeted audience. We found that the students' dual perspectives brought new aspects to the existing practices of resource developers, including offering insight into how students learn, internal knowledge of those who have attended the same module a year before, and new methods for the evaluation of the produced resources.

In terms of the critical idea of *participation* in the community of resource developers, we saw that some students chose or found themselves eventually fully *participating* and some others *partially participating*. Most of the students faced challenges in their engagement with the project. Some of them dealt with these difficulties by gaining ownership of the overall practice and without marginalising themselves. These students chose the participation as a mode of *engaging*. They *aligned* critically with the rules while they used their experience (*imagination*) to make these rules part of their practice. Thus they found themselves located legitimately in the community of developers. This was not the case with other students, who did not manage to, or choose not to, gain ownership of the overall practice. In particular, those who developed resources for non-mathematics students found it difficult to align themselves with the rules of modules they did not know. Their previous experience (imagination) could not help them as they found themselves working in a less familiar context.

7.2. *Suggestions for future implementations*

Suggestions for how versions of such a project could be improved in the future have come both directly from the students and from analysis of the transcripts. First, the students made the direct suggestion that it would be useful to have contact with and feedback from the students who will be using the resources. Although time constraints may not always permit formal feedback, it would be useful if the students creating resources observed some lectures and labs, and had an opportunity to discuss with module students in the early stages of resource

development. When possible, it would also be useful for the resource developers to have at least the opportunity to observe the module students interacting with the resources, even if a formal evaluation is not possible. Second, students had various opinions about the value of group work. All of the students valued the interaction with other students on the project in some contexts and to some degree. However, some of them valued being part of a large group, especially Bridget and Victor, whereas Andy did not find the meetings as a whole group useful, and Helen found them at times confusing and distracting. From the viewpoint of logistics, as well as the supervising staff time commitment, it seems therefore that in the future, it may be advisable to work with somewhat smaller groups of dissertation students at one time, though not abandoning the group aspect altogether.

From examining the data from the interviews, it emerges that only two students discussed having read the statistics education literature. These students, Helen and Victor, found this reading very helpful. It is not uncommon for lecturers to be unfamiliar with the education literature in their area, but we propose that it would have been useful for all of the students to read some key papers at the start of their dissertations. This has the potential for three benefits. First, it would give them something active to do at the start of the dissertation while the consulting process had not yet produced clear objectives, and would give them some useful conceptual structures around which they could organise their dissertations. Second, reading about the goals of statistics education could help them to direct their own learning of statistics. Third, it would give them supporting materials they could refer to in making convincing arguments to the lecturing staff about what should be changed in the way the resources are created or the module is run.

In a similar way, an examination of the data suggests that it might have been useful to have students read material during the first few weeks about running effective consulting projects (see for example [20]). Although there is evidence that students developed some skills in consulting, there is also evidence that they did not always recognise the challenges they faced in their consulting roles as common consulting challenges, such as working under time constraints and having to take time at the start of a project to clarify what exactly needs to be done. Reading relevant literature might help them to recognise the stages of a consulting project, including the first stage in which it is necessary to clarify goals. It might also help them run more efficient meetings and come to those clearer goals more quickly.

7.3. *Contributions to theory and steps forward*

In terms on the aspects of statistical thinking, our analysis contributed a sixth item to the list suggested by Pfannkuch and Wild ([12]). This aspect regards the *awareness of multiple approaches*, which covers a recognition that there are varied practices among statisticians, and that a given dataset may be analysed through different valid methodologies. This also was seen as a particular stumbling block for new learners of statistics, perhaps related to an expectation that statistics will be more like mathematics than it is in practice.

Furthermore, this study contributed to the evaluation of student knowledge enhancement in the frame of project work by introducing the social aspect of this knowledge development. In these terms not only students' learning was evaluated, but also how students' participation, perspectives and identity contributed to this learning. We initiated the analysis with the assumption that students were joining the community of university statistics teachers in the activity of resource development, and they would experience the dual identity of student and developer. The analysis revealed that there is a spectrum in students' perspectives that goes further

than the duality student-developer, including mathematics vs non-mathematics student identities. Furthermore, a diversity in lecturers' perspectives was revealed, indicative of the internal heterogeneity in the community of university statistics teachers. On the basis of our analysis, we can claim that the institutional context in which the project takes place affects the formation of and the interaction between these different identities. This is something that should be considered not only in future implementations of similar projects but also in the way these implementations are evaluated.

Another contribution of the study is to initiate the discussion about how existing practices are affected when *outsiders* - in our case, students - join a community without belonging to it. This is what Wenger called *brokering*, which is the multimembership that allows the transfer from one practice to another (p. 105). The same might be applicable in the case of lecturers if we consider them as belonging in different communities (e.g. mathematicians, non-mathematicians, statisticians etc.). The results of the analysis we present here on this aspect just scratch the surface and should be further investigated in future research.

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Appendix A. Interview questions: End of second phase

(1) Please describe your project.
(2) What have you learned from your project about statistics and research design?
(3) Can you give an example of a new topic or a topic where your understanding has been improved by this project?
(4) What have you learned about the way these concepts are used in (discipline or subject)? Example?
(5) What have you learned about the way statistics and/or research design are taught and learned in this discipline? Example?
(6) Do you think that you have improved the resources for students on the module? Please explain.
(7) Do you believe the resources you produced support the teaching in the module?
(8) Did you enjoy producing these resources?
(9) What part of the resource production did you like most?
(10) Least?
(11) What part of the resource production was most difficult?
(12) Most straightforward?
(13) What support did you get in producing these resources that was particularly important?
(14) What support would you have liked to have that you did not get?
(15) Can you give some examples of how the content of this module could be used in a research context?
(16) How confident would you feel providing consultation to a student researcher in this subject about their research project?
(17) What implications does your experience have for the flowchart project, which aims to produce a statistics resource for students in many disciplines?
(18) How would you describe your collaboration and interactions with other students and staff members during the project?
(19) Were you able to give the staff any insights about the student perspective?
(20) Did you learn anything about the staff perspective from this project?
(21) Can you give some examples of times where there was good communication between students and staff?
(22) Places where the communication could be improved? How?
(23) Why did you choose this project over a more conventional project, and what did you imagine it would be like?
(24) Has this project lived up to your expectations? Please explain.
(25) What do you think has been best about this project?
(26) What should be improved in future projects of this type?
(27) Do you have any further comments about the project that you would like to share with us?