This is an Accepted Manuscript of an article published in Journal of Applied Biomechanics, 2020, available online:
https://doi.org/10.1123/jab.2020-0069

Version: Accepted for publication

Experiences of undergraduates publishing biomechanics research

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ABSTRACT

The aim of this study was to investigate student experiences of publishing undergraduate research in biomechanics. A total of twenty-nine former students with experience of publishing peer-reviewed undergraduate biomechanics research completed an online survey regarding their perceived benefits, level of involvement, and experiences in aspects of the research process. On average, students perceived their experiences to be 'largely helpful' or greater in all aspects. Areas were identified corresponding to: the greatest perceived benefits (e.g. understanding of the research process); the least perceived benefits (e.g. statistical analysis skills); the greatest student involvement (e.g. reading relevant literature); and the least student involvement (e.g. developing hypotheses and/or methods). A thematic analysis of open question responses identified themes relating to: future career; skills; scientific process; intra / interpersonal factors; and pedagogy. Common intended learning outcomes may be achieved through involvement in the research process independently of the level of staff involvement. Staff should be encouraged to involve students in publishable biomechanics research projects where this is possible without compromising research standards and should explore ways of recreating the publishing process internally for all students.

Keywords: dissertation, student, sports, teaching, Higher Education

INTRODUCTION

Staff-student partnership has beneficial effects on many factors related to teaching and learning. These include employability skills and attributes, a deepened understanding of and contribution to the academic community, and raising the profile of research in teaching and learning[1,2]. According to the National Union of Students, "partnership is about investing students with the power to co-create"[3]. One common way of facilitating staff-student partnerships is through undergraduate involvement in research projects, which has been called the pedagogy for the 21st century[4]. Whilst staff-student research partnerships have potential extrinsic (*e.g.,* acceleration in research productivity[5–7]) and intrinsic (*e.g.,* motivation and enjoyment[6,8]) benefits for staff and institutions, this study will focus on the experiences of students in such partnerships.

Several frameworks have presented the ways in which students may be engaged in research. The most widely applied is that developed by Healey[9], expanding upon Griffiths' research–teaching nexus[10]. The model has two axes (Figure 1): one distinguishes between students as audience or participants; while the second distinguishes between emphasis on research content or research processes and problems. This categorises the four main ways in which undergraduates can be engaged with research and inquiry as research-led (*e.g.,* learning about current biomechanics research), research-oriented (*e.g.,* developing biomechanics research skills), research-based (*e.g.,* undertaking biomechanics research), or research-tutored (*e.g.,* discussing biomechanics research). A vast body of research supports effective outcomes when students produce their own knowledge through inquiry-based activities (the research-based quadrant; Figure 1)[11,12]. One associated strategy for linking research and teaching is ‘giving students the opportunity to work on research projects alongside staff’[9]. Publication with undergraduates can be facilitated through multiple opportunities for staff-student collaboration and by incorporating high-quality research projects with publication potential into specific courses[13–15]. Student effort in research projects has been linked positively to both intent to publish and the time spent on the project by staff[16].

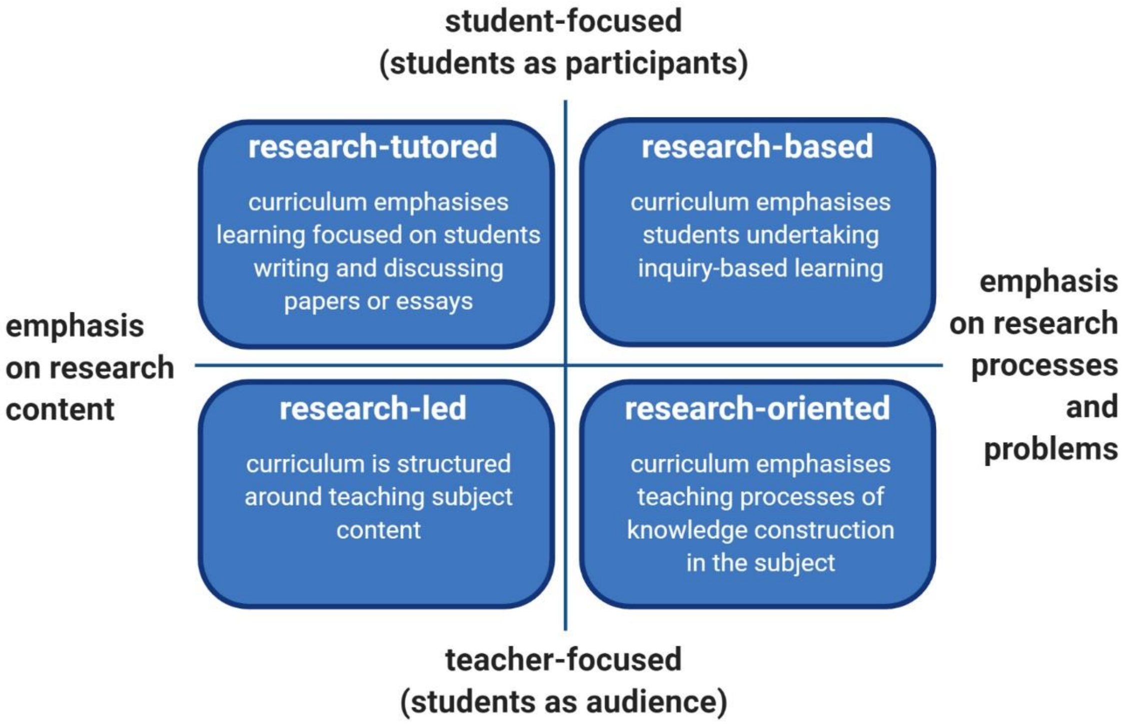

Figure 1 - Research-teaching nexus. Adapted from Healey[9].

Literature considering student experiences of working on published research is largely anecdotal (e.g. the research topic ‘Engaging Undergraduates in Publishable Research: Best Practices’ in frontiers in Psychology[15]). Matthews and Rosa reflected on their own experiences, discussing the perceived benefits (*e.g.* confidence, work ethic, critical thinking, career preparation, and publication) and challenges (*e.g.* interpersonal dynamics, procrastination, and project work continuing after graduation)[17]. Golding et al. interviewed staff and students to investigate summer undergraduate research as a potential pathway to publication in psychology[18]. Their constructed themes were similar to the experiences of Matthews and Rosa[17], reflecting numerous benefits (*e.g.* work readiness and additional research experience, networking and teamwork, publication) and challenges (*e.g.* equity of opportunities) of the program.

These experiences are specific to psychology, whereas the discipline is an important mediator in constructing links between research and teaching[19,20]. Multi-disciplinary but single institution survey results from Weiner and Watkinson support these benefits[21]. Students publishing in an undergraduate-only journal gained information literacy knowledge and intended to publish articles in the future. To date, no research has focused on similar experiences within biomechanics. This remains necessary, especially given the unique nature of data collection and analysis techniques taught in undergraduate biomechanics courses[22]. The majority of pedagogical biomechanics research has focused on course concepts and technology, rather than student learning experiences[23–26].

The purpose of this study was therefore to investigate student experiences of publishing undergraduate research in biomechanics. Although the study was largely exploratory in nature, it was primarily hypothesised that students would perceive their involvement in published undergraduate research as beneficial across all aspects of the research process. It was further hypothesised that the greatest benefits would be perceived when staff and students worked collaboratively, and would include self-confidence, academic / research skills, career preparation, and a sense of accomplishment.

METHODS

Participants

Twenty-nine former students with experience of publishing peer-reviewed undergraduate biomechanics research were recruited via the author's professional and social media networks. Fugard and Potts claimed that a sample size of twenty-six is required for 80% chance of observing at least five instances of a theme that has 25% prevalence in the population[27]. However, the frequency of observations are of lesser importance in comparison to fruitful experiences of shared meaning[28,29], and as few as ten participants may be sufficient for this purpose[30]. Each participant's authorship of published research undertaken as an undergraduate student (including peer-reviewed international conference proceedings) was independently verified. Study details were explained to each participant and informed consent obtained in accordance with the ethics committee of the School of Health and Sports Sciences, University of Suffolk, UK. All procedures were conducted according to the Declaration of Helsinki for studies involving human participants. No incentives were offered for participation, nor were there any penalties for not participating.

Data Collection

Each participant completed an online survey hosted by www.surveymonkey.com (SurveyMonkey Inc., San Mateo, California, USA). The survey was adapted from two previous investigations, including the three section (multiple choice; Likert scale opinion assessment; narrative exploration) survey by Mabrouk and Peters[31] and the Likert scale questions of Salsman et al.[16]. These surveys have successfully elicited rich qualitative and quantitative data regarding students' experiences of staff-student research partnerships.

The present study's survey was composed of three sections. In Section 1 (perceived benefits; 16 questions) participants rated the perceived benefits from their direct involvement in the published project on a Likert scale from 'not at all helpful' to 'extremely helpful'. In Section 2 (level of involvement; 8 questions) participants rated their level of involvement in aspects of the research progress on a Likert scale from 'My supervisor/others did all of the work' to 'I did all of the work'. In Section 3 (narrative exploration; 5 questions) participants responded to open questions about their experiences during the project. All questions and answer options are listed in Table 1.

Data Analysis

Responses in Section 1 (perceived benefits) were scored from 1 for '*not at all helpful*' to 5 for '*extremely helpful*'. Section 2 (level of involvement) was scored from 1 for '*My supervisor/others did all of the work*' to 5 for '*I did all of the work*'.

Table 1. Survey questions and response options.

Section 1 (Perceived Benefits)	
Has your undergraduate research been helpful in improving your:	
Options: not at all helpful; a little bit helpful; moderately helpful; largely helpful; extremely helpful; or not applicable to my project	
Question 1	Ability to work independently
Question 2	Ability to collaborate with other researchers
Question 3	Understanding of the research process
Question 4	Self-confidence
Question 5	Sense of accomplishment
Question 6	Interest in your field
Question 7	Knowledge of ethical standards
Question 8	Ability to locate and identify relevant literature
Question 9	Ability to read and understand primary literature
Question 10	Ability to integrate theory and practice
Question 11	Critical evaluation of methods in literature
Question 12	Ability to solve technical or procedural problems
Question 13	Ability to collect data according to a plan
Question 14	Data analysis skills
Question 15	Statistical analysis skills
Question 16	Written communication skills
Section 2 (Level of Involvement)	
Please rate your involvement on the following tasks relating to the final published work:	
Options: My supervisor/others did all of the work; I did a small amount of the work; Myself and my supervisor/others did a roughly equal share of the work; I did most of the work; or I did all of the work	
Question 1	Reading relevant literature
Question 2	Developing hypotheses and/or methods
Question 3	Recruiting participant(s)
Question 4	Collecting data
Question 5	Data analysis
Question 6	Statistical analysis
Question 7	Interpretation of the findings
Question 8	Preparing the written report
Section 3 (Narrative Exploration)	
Question 1	What was the most memorable experience you had during your time working on the project?
Question 2	How did working on the project affect your personal growth
Question 3	What was the most difficult aspect of the research project experience?
Question 4	What do you believe you learned (if anything) that was unique to your experience in this project that you did not learn in the traditional academic classroom?
Question 5	Any other comments?

All statistical analysis was performed in JASP Version 0.10 (Amsterdam, Netherlands), with violin plots generated using the vioplot package[32] in R Version 3.6.2 (R Core Team, 2019). Non-parametric analyses were performed due to the non-normality (Shapiro-Wilk test: $p \leq 0.025$) and ordinal nature of all Likert scale response data. Friedman tests[33], with Conover's post-hoc comparisons[34,35], identified differences between survey items (*i.e.* which aspects of the research process had greater or lesser perceived benefits or levels of involvement). A Holm correction[36] controlled for multiple comparisons, with a p-value < .05 indicating statistical significance. Kruskal-Wallis tests[37] reported the effect of levels of involvement on potentially related perceived benefits (*e.g.* effect of involvement in preparing the written report on perceived benefits in written communication skills; all tests listed in Table 2). The false discovery rate was controlled for multiple comparisons via the Benjamini-Hochberg procedure with a critical value for false discovery rate of .25 [38].

All open responses in Section 3 (narrative exploration) were analysed in ATLAS.ti Version 8.4.24.0 for Windows (ATLAS.ti Scientific Software Development GmbH, Berlin, Germany) using a thematic analysis[39]. Following familiarisation, the data were coded using phrases as the basic unit of analysis. These initial codes were sorted into themes and subthemes, which were then reviewed using thematic maps as an aid.

RESULTS

Quantitative

A significant (χ^2 = 49.058; df = 15; p < .001) between survey item effect was reported for perceived benefits (Figure 2). Benefits relating to '*understanding of the research process*' (median [interquartile range]: 5 [4.5, 5]) were perceived to be greater than those relating to '*statistical analysis skills*' (4 [3, 5]; t = 4.111; p = .006), '*critical evaluation of methods in literature*' (4 [3, 5]; t = 3.817; p = .019), and the '*ability to collaborate with other researchers*' (4 [3, 5]; t = 3.695; p = .029). Benefits relating to '*statistical analysis skills*' were also perceived to be less than those relating to the '*ability to work independently*' (5 [4, 5]; t = 3.747; p = .024) and '*sense of accomplishment*' (5 [4, 5]; t = 3.730; p = .026). No other significant differences in perceived benefits were reported (.017 ≤ t ≤ 3.487; .063 ≤ p ≤ 1.000).

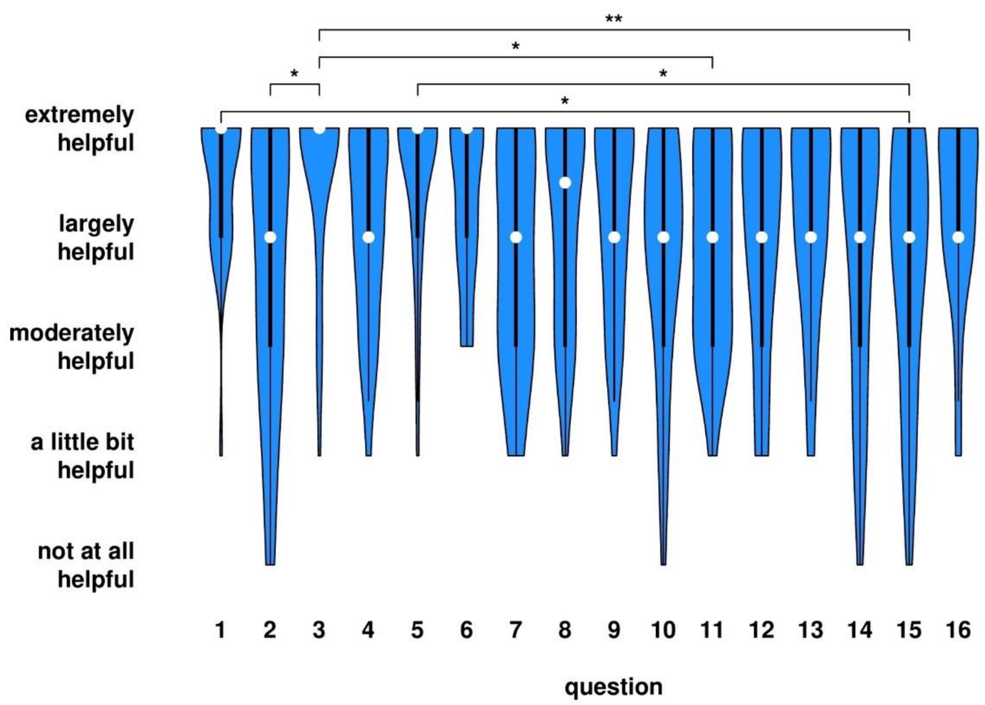

Figure 2 - Participant responses to perceived benefits of involvement in published undergraduate research. White circle: median; black bar: interquartile range; blue density: frequency of each response. Q1: ability to work independently; Q2: ability to collaborate with other researchers; Q3: understanding of the research process; Q4: self-confidence; Q5: sense of accomplishment; Q6: interest in your field; Q7: knowledge of ethical standards; Q8: ability to locate and identify relevant literature; Q9: ability to read and understand primary literature; Q10: ability to integrate theory and practice; Q11: critical evaluation of methods in literature; Q12: ability to solve technical or procedural problems; Q13: ability to collect data according to a plan; Q14: data analysis skills; Q15: statistical analysis skills; Q16: written communication skills. * p < .05; ** p < .01.

A significant ($\chi^2 = 26.107$; df = 7; $p < .001$) between survey item effect was reported for level of involvement (Figure 3). Level of involvement in '*developing hypotheses and/or methods*' (3 [2.5, 4]) was lower than that in '*reading relevant literature*' (4 [3, 5]; t = 3.740; $p = .007$), '*recruiting participant(s)*' (4 [3, 5]; t = 3.269; $p = .034$), and '*data analysis*' (4 [3, 5]; t = 3.206; $p = .041$). No other significant differences in levels of involvement were reported (.000 ≤ t ≤ 2.954; .088 ≤ p ≤ 1.000). Levels of involvement had no significant effects on potentially related perceived benefits ($.319 \le \chi^2 \le 9.000$; Table 2).

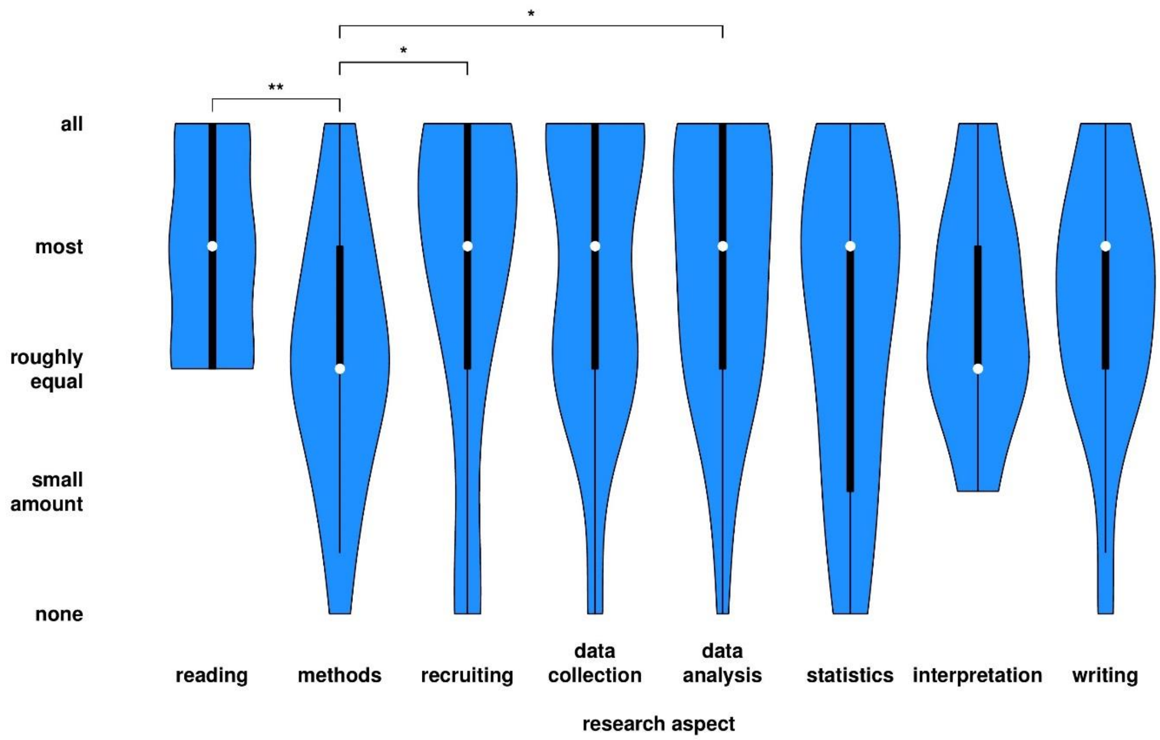

Figure 3 - Participant responses to their level of involvement in aspects of published undergraduate research projects. White circle: median; black bar: interquartile range; blue density: frequency of each response. * $p < .05$; ** $p < .01$.

Qualitative

Narrative data highlighted that participants generally experienced a strongly positive and beneficial undergraduate research experience. The findings of the thematic analysis are presented as a series of five themes (see Figure 4 for a thematic map): career (discussed in 22 question responses [q] by 17 participants [n]); skills (see subthemes outlined below); scientific process (n = 14, q = 17), intra / interpersonal (see subthemes outlined below); and pedagogy (n = 9, q = 9). The skills theme consisted of three subthemes: academic skills (n = 20, q = 32); technical skills (n = 15, q = 27); and organisational skills (n = 11, q = 15). The intra / interpersonal theme consisted of both intrapersonal factors and interpersonal factors. Intrapersonal factors were confidence (n = 15, q = 17), accomplishment (n = 15, q = 15), and independence (n = 6, q = 6). Interpersonal factors were supervision (n = 9, q = 10) and interpersonal skills (n = 8, q = 10). The most frequent benefits mentioned in response to open questions related to participants' careers and confidence (Table 3). Most frequent challenges related to academic, organisational, and technical skills.

Table 2. Kruskal-Wallis tests for the effect of student / staff involvement levels on students' perceived benefits of their involvement in published undergraduate biomechanics research.

all correlations: Chi-square effect size (*p value*)	**reading relevant literature**	**developing hypotheses and/or methods**	**recruiting participant(s)**	**collecting data**	**data analysis**	**statistical analysis**	**interpretation of the findings**	**preparing the written report**
ability to work independently	2.835 (*.242*)	8.179 (*.085*)	4.171 (*.383*)	1.710 (*.635*)	4.047 (*.400*)	2.670 (*.614*)	.944 (.815)	2.555 (.635)
ability to collaborate with other researchers	1.916 (*.384*)	8.064 (*.089*)	4.004 (*.406*)	5.952 (*.114*)	2.308 (*.679*)	.951 (*.917*)	.319 (.956)	1.917 (.751)
understanding of the research process	4.591 (*.101*)	7.109 (*.130*)	3.078 (*.545*)	2.187 (*.534*)	7.167 (*.127*)	3.810 (*.432*)	6.903 (.075)	6.557 (.161)
self-confidence	.964 (*.617*)	6.569 (*.161*)	5.920 (*.205*)	8.145 (*.043*)	6.075 (*.194*)	3.701 (*.448*)	1.456 (.692)	1.669 (.796)
sense of accomplishment	2.517 (*.284*)	2.414 (*.660*)	3.296 (*.510*)	5.771 (*.123*)	3.337 (*.503*)	2.465 (*.651*)	4.854 (.183)	4.874 (.300)
interest in your field	.652 (*.722*)	.590 (*.964*)	9.000 (*.061*)	7.181 (*.066*)	5.106 (*.277*)	3.060 (*.548*)	4.838 (.184)	2.118 (.714)
knowledge of ethical standards	-	4.404 (*.354*)	-	-	-	-	-	-
ability to locate and identify relevant literature	3.062 (*.216*)	-	-	-	-	-	-	-
ability to read and understand primary literature	.923 (*.630*)	-	-	-	-	-	-	-
ability to integrate theory and practice	4.042 (*.133*)	-	-	-	-	-	3.283 (.350)	5.848 (.211)
critical evaluation of methods in literature	2.658 (*.265*)	4.037 (*.401*)	-	-	-	-	-	-
ability to solve technical or procedural problems	-	-	-	.715 (*.870*)	7.036 (*.134*)	-	-	-
ability to collect data according to a plan	-	7.355 (*.118*)	-	1.324 (*.723*)	-	-	-	-
data analysis skills	-	-	-	-	4.476 (*.345*)	-	-	-
statistical analysis skills	-	-	-	-	-	4.177 (*.383*)	-	-
written communication skills	-	-	-	-	-	-	-	1.851 (.763)

Note: Controlling the false discovery rate (for multiple statistical tests) via the Benjamini-Hochberg procedure[24] with a critical value for false discovery rate of .25 reported no significant effects. Tests were only conducted for potentially related variables (*e.g.* effect of involvement in preparing the written report on perceived benefits in written communication skills.

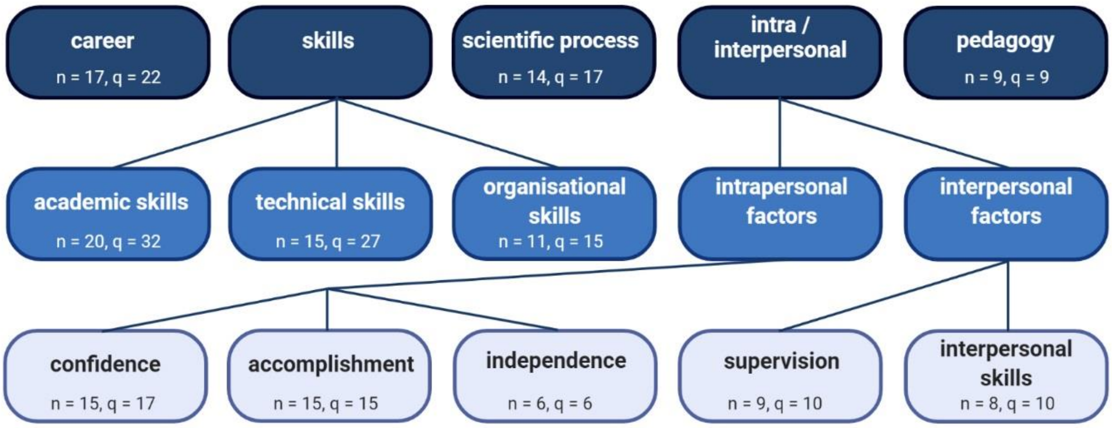

Figure 4 - Thematic map of themes and subthemes emerging from experiences of undergraduates publishing biomechanics research. n: number of participants discussing the (sub)theme; q: number of question responses discussing the (sub)theme.

Table 3. Theme frequency (% of total responses for that theme) in response to each open question.

	question				
theme	memorable	growth	difficult	unique	other
career	1 (5)	13 (59)	-	2 (9)	6 (27)
academic skills	2 (6)	4 (13)	12 (38)	14 (44)	-
technical skills	8 (30)	2 (7)	6 (22)	9 (33)	2 (7)
organisational skills	1 (7)	2 (13)	7 (47)	5 (33)	-
scientific process	4 (24)	4 (24)	1 (6)	8 (47)	-
confidence	1 (6)	14 (82)	-	2 (12)	-
accomplishment	11 (73)	2 (13)	-	-	2 (13)
independence	-	3 (50)	2 (33)	1 (17)	-
supervision	5 (50)	-	1 (10)	1 (10)	3 (30)
interpersonal skills	6 (60)	1 (10)	2 (20)	1 (10)	-
pedagogy	-	-	1 (11)	5 (56)	3 (33)

Participants perceived benefits for their future career, particularly within academia, as a result of their involvement in the published research project. This was largely through developing an interest in research and related career aspirations (*e.g.* "*It encouraged me to further engage in research and it sparked a passion for biomechanics in particular*") and/or through enhancing research-related skills that remained beneficial beyond completion of the project (*e.g.* "*Today I am a Ph.D. student because of what I learning* [sic] *during my undergraduate project.*" and "…these skills have proven valuable in my graduate training."). Indeed, 68% of career responses related to areas of growth or unique experiences not provided through alternative teaching methods. No negative career-related comments were provided (Table 3).

Skills-related comments were the most common responses when discussing difficulties and unique experiences (Table 3). Technical skills such as specialist equipment or data analysis software were often mentioned as the most memorable experience (*e.g.* "*Pilot testing and learning to use the motion capture equipment*"). The academic skills mostly related to writing, reviewing the scientific literature (*e.g.* "*how to organise and annotate literature to make it easy to retrieve key information*"), and applying theory to practise. Organisational skills generally related to unique and challenging experiences of time-management, organising data collection, and participant recruitment:

> "*In terms of data analysis the project really enhanced my ability to sort through data and setting targets for when the tasks should be finished by further enhanced my ability to work through the data more efficiently.*"

Participants reported that the project enhanced their understanding of the research process and scientific enquiry (*e.g.* "*I had a better understanding of what research was and how it was undertaken.*"). Numerous participants also developed an increased awareness of the required standard of published work (*e.g.* "*The level of work required to jump from an undergrad project to something you actually wanted others to read*"). Other comments highlighted the frequency and importance of mistakes or problems during scientific research:

> "*The experience made me aware of the fact that research is full of possible human error.*"

Involvement in a published research project provided many participants with a greater self-confidence, sense of accomplishment, and feeling of independence. Comments relating to confidence most frequently (82%; Table 3) featured in relation to personal growth (*e.g.* "*I was more confident in my ability to think on my feet after conducting undergrad research.*"). Sense of accomplishment was the single most common type of memorable experience, frequently relating directly to the final publication or presenting at a conference:

> "*I presented pilot study results at an international conference and had numerous researchers commend me for my work, with many taking photos of my poster to help with their own projects.*"

Both supervision (50%) and interpersonal skills (60%) most frequently related to memorable experiences within the project. Comments on supervision were mostly positive (*e.g.* "*I think the differential was I had a good research group and an excellent supervisor in my undergraduate*") except for one negative experience ("*generally poor support from supervisor*"). Interpersonal skills generally related to collaboration (*e.g.* "*Carrying out a research project through to a publishable standard through a collective effort.*") or communication with participants (*e.g.* "*Ability to work with athletes in an applied setting.*").

Pedagogical remarks typically occurred in relation to unique experiences (56%) or additional comments (33%). Most comments compared the learning experiences during the research project and alternative teaching strategies. For example, "*Independent lead research, transition from being drip feed everything to taking full responsibility was challenging*" and "*In traditional academic classrooms you don't learn how to adapt and pivot when undertaking research*".

Participants offered contrasting opinions on whether the experience would be beneficial for all students. Positive statements included "*it is important to allow the students to be able to learn and try specialised methods in their research projects that they have not been exposed to previously*". Two participants raised negative concerns, such as "*I feel that not all undergrads should conduct research, perhaps those that show promise and initiative. I can see how research could become irrelevant or tainted by those who don't have the drive to criticize their own works.*". Potential implications for the wider discipline were also discussed:

> "*Although it was personally beneficial to me, I don't believe it is that beneficial to the field and progress in sports biomechanics. [Undergraduate] dissertations are*

supposed to be a student's first experience of doing research. It is also supposed to be largely independent work. When you put these together, it is difficult to see how work can be of a standard that merit publication in journal if the goal is to advance the field. Sports science journals are now littered with… student papers as academics scramble to publish their students' work to improve their research record"

DISCUSSION

The purpose of this study was to investigate student experiences of publishing undergraduate research in biomechanics. It was primarily hypothesised that students would perceive their experience as beneficial across all aspects of the research process. On average, students perceived their experiences to be 'largely helpful' or greater in all aspects. It was further hypothesised that the greatest benefits would be perceived when staff and students worked collaboratively, and would include self-confidence, academic / research skills, career preparation, and a sense of accomplishment. Areas were identified corresponding to the greatest (e.g. understanding of the research process) and least (e.g. statistical analysis skills) perceived benefits and the greatest (e.g. reading relevant literature) and least (e.g. developing hypotheses and/or methods) student involvement. Themes were identified in narrative responses relating to future career, skills, scientific process, intra / interpersonal factors, and pedagogy.

When interpreting the results, it is important to consider survivorship bias. Survey respondents are more likely to have experienced positive effects and subsequently remained in academia than those who did not respond or were not identified through the largely academic networks utilised for recruitment. It should be remembered that the present study was largely exploratory in nature. Participant recruitment, and hence statistical power, was limited by the relatively small population size of interest (former students with experience of publishing undergraduate research) and so any lack of significant effect should not be interpreted as evidence of no effect. The sample was sufficient to enable 'theoretical saturation' via the thematic analysis[30,40].

Both quantitative and qualitative data support the primary hypothesis that students would perceive their experience as beneficial across all aspects of the research process. These findings provide support for research-based student opportunities within biomechanics. These can be designed around inquiry-based activities in which the scope for interactions between teaching and research is deliberately exploited and the opportunity for publication is presented[9]. In this regard, the current findings are in agreement with previous research in other disciplines[17,18,21].

Students perceived the greatest benefits in general concepts such as understanding the research process and their sense of accomplishment. They perceived the least benefits in specific research skills such as statistical analysis skills and critical evaluation of methods in the literature. This difference may relate to the often relatively narrow range of techniques experienced during a single research project in comparison to those taught in undergraduate programmes[22]. Undergraduate research also appears to be more beneficial for developing independent rather than collaborative skills. This is likely due to the independent nature of many undergraduate projects. These findings contrast with those of Salsman et al.[16] for non-published undergraduate maths and science research, perhaps due to unique features of research with publication potential.

Participants in the current study reported the greatest levels of involvement in time-consuming aspects such as reading relevant literature, recruiting participants, and analysing data. They reported the lowest levels of involvement in developing hypotheses and/or methods, a critical design stage of the research process. This corroborates previous results for non-published undergraduate research in maths and science[16]. It is possible that the greater perceived benefits in broad outcomes such as sense of accomplishment relate to the greater student involvement in less technical aspects of biomechanics research. A lower reported level of student involvement may alternatively reflect greater staff involvement, something previously linked to beneficial outcomes[1,2,16]. However, effects of student / staff involvement in specific tasks on potentially related perceived benefits were not statistically significant. The hypothesis that the greatest benefits would be perceived when staff and students worked collaboratively can therefore not be confirmed.

Themes identified from qualitative data were similar to those identified in similar studies within other disciplines. This is despite the known effect of discipline characteristics on links between teaching and research[19,20]. For example, it was unknown what effect the unique nature of data collection and analysis techniques taught in undergraduate biomechanics programs[22–26] would have on student research experiences. Indeed, in the present study technical skills such as specialist biomechanics equipment or data analysis software were often mentioned as students' memorable experiences of the research process. Equivalent themes to confidence, academic skills, career, and accomplishment have recently been identified in psychology[17,18]. The themes broadly covered all aspects of the research process, again supporting the primary hypothesis. Whilst the majority of comments were positive, it is noteworthy that the three subthemes relating to skills (academic, organisational, and technical skills) were the most frequent difficulties encountered. Both qualitative and quantitative responses suggest that participants perceived benefits in these skills and so the challenges reported should not be considered as a negative outcome. Narrative responses suggest that the demand for independent skill execution may reflect the greatest difference between taught content and research project tasks. Taken together, the data only partially support the secondary hypothesis that students would perceive the greatest benefits in self-confidence, academic / research skills, career preparation, and their sense of accomplishment. It should be noted that career responses (and the associated Likert scale questions) primarily related to academia rather than industry. Likewise, all skills-related benefits are reported as perceived benefits and it is not clear how these skills were subsequently applied. An evaluation of subsequent career destinations was beyond the scale of this study. Despite research and inquiry skills being central to professional careers in industry as well as academia[41], a large proportion of students do not perceive that they will need them[42]. The current results suggest that undergraduate research involvement may help students to appreciate the potential benefits for future careers.

The identified themes support the application of a number of Healey's strategies for linking research and teaching[9]. For example: 'scientific process' supports '*developing students' appreciation of research in the discipline*'; 'academic skills' supports '*developing students' research skills*'; and 'supervision' and 'interpersonal skills' both support '*giving students the opportunity to work on research projects alongside staff*'. It seems that these outcomes may be achieved through involvement in the research process independently of the level of staff involvement, although staff involvement has previously been linked positively to student effort[16]. Staff wishing to utilise '*assignments that involve elements of research processes*' or '*teaching and learning processes that simulate research processes*', two more of Healey's[9] strategies, should make informed decisions regarding their level of involvement in each aspect of the research process based upon pedagogical principles.

Engaging students in biomechanics research projects with publication potential can have beneficial consequences for the students and should therefore be recommended where possible. Student activities within such projects should be constructively aligned to intended learning outcomes[43]. It is unclear to what extent these results can be generalised to wider undergraduate biomechanics cohorts. Students engaging in publishable research likely differ in ability and/or experience to those conducting typical student projects, and as such the reported perceived benefits may differ to those experienced by entire cohorts[44]. One participant suggested that the opportunity to work on publishable research projects should be reserved for "*perhaps those that show promise and initiative*". Whilst it may be true that not all students have the potential to publish their research, the present results support the inclusion of research-based teaching within undergraduate biomechanics curriculum design. Departmental case studies highlight the possibility of research with all students as a course distinguishing feature while also creating a specialist pathway for selected students with publication potential[11].

Indeed, the 'student as scholar' model requires a culture of inquiry-based learning infused throughout the entire curriculum[45]. This necessitates a pedagogical transition from 'telling students what they need to know' to 'encouraging students to seek and discover new knowledge'[45,46]. It may be beneficial to design research opportunities into formative and summative processes for many or all students in ways that reflect the publishing process (*e.g.,* undergraduate research journals, student research conferences and exhibitions)[21,47,48]. Student involvement in published biomechanics research appears to be particularly successful in emphasising the uncertainty of the task and facilitating the experience of scientific productivity[46]. Healey and Jenkins suggest progressively developing students' understanding of research throughout the multi-year curriculum[49–51]. This progression would see introductory courses present knowledge as created, uncertain and contested. Advanced courses would progressively develop students' capacities to do research, leading to a graduating year (capstone courses) in which students carry out a summative research project, collaborating with staff in a similar manner to the experiences reported in the current study[49–51]. For the benefits reported in this study, it may be constructive to create a particular period of the year when students can focus entirely on undergraduate research, or to ensure timetables allow dedicated time for research activities[11]. Future investigations of potential confounding variables such as research group size and supervisor experience may provide further insight[6].

Given the lower perceived benefits relating to statistical analysis, it may be prudent to focus on related methods and techniques in the intermediate years of study leading up to any summative research project. Rather than a linear process from highly structured to highly independent, it has been recommended that students be given independence in an early project to build motivation, similarly to some of the reported benefits in the current study[11]. Alongside the multi-year model discussed above, this approach would see students firstly build motivation through guided and open inquiry, before focusing on methods and techniques, and finally undertaking independent (or collaborative) research projects prior to graduating. Given the emergence of 'career' as a theme within the current study, it may be beneficial for staff to explicitly link undergraduate research and inquiry to student employability or to involve students in industry-based research projects[11,52].

At an institutional level, the Council on Undergraduate Research recommends: adding student research mentoring into mission statements and strategic plans; building student research mentoring into workload; rewriting tenure, promotion, and review documents to value student research mentoring; honouring staff-student collaborations with targeted internal research funds; providing time for research-based curriculum redesign; establishing awards to honour student research mentoring; and establishing best practices in student research mentoring[53]. Departmentally, integration of research and teaching organisational structures may facilitate a more integrated approach, and broader definitions of what counts as research may make it easier for staff to engage undergraduates in research and inquiry[11]. The ideal culture of students wanting and expecting to participate in research may be facilitated by transparent rules on the quality of work necessary for dissemination, and the involvement of all members of the university community in celebrating undergraduate research outputs[52]. This latter suggestion may extend the sense of 'accomplishment' identified in the present study beyond only those students publishing peer-reviewed research. Readers are directed to Jenkins et al. for departmental and institutional intervention case studies[50]. Resources to support staff and students in collaborative undergraduate research are available via the Council on Undergraduate Research (www.cur.org). For wider literature on the integration of research and teaching beyond student research projects, readers are encouraged to explore the entirety of Healey's research-teaching nexus (Figure 1)[9].

In summary, students reported positive experiences of publishing undergraduate biomechanics research, with their level of independence varying across the process. Common intended learning outcomes may be achieved through this involvement in the research process. Student experiences related to their future career, skills, the scientific process, intra / interpersonal factors, and pedagogy. Such research-based teaching strategies are especially effective in achieving broad non-technical objectives such as an understanding of the research process, sense of accomplishment, and ability to work independently. As such, staff should be encouraged to involve students in biomechanics research projects through research-based curriculum design where it is possible to do so without compromising research standards and should explore ways of recreating the publishing process internally for all students.

ACKNOWLEDGEMENTS

The author has no conflicts of interest to disclose.

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