BMC Medical Education

RESEARCH Open Access

The impact of a curriculum-based research training program on medical students' research productivity and future research interests: a longitudinal study

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Abstract

Background Incorporating scientific research into undergraduate medical education is necessary for the quality of future health care. However, providing rigorous research training to a large number of medical students at one institution remains one of the major challenges. The authors studied the impact of a curriculum-based Research Training Program (RTP) for all undergraduate students at Zhejiang University School of Medicine (ZUSM) on research productivity and future research interests.

Methods Medical students ($n=2,213$) from ZUSM who completed the course of RTP between 2013 and 2020 were studied. The authors measured the academic performance, research publications, and research projects of students across years, and evaluated potential factors that contribute to student research productivity and increased interest in future research.

Results Across the years, there was an increase in the number of student publications, a greater proportion of students with publications, and a greater proportion of projects involving three or more students ($P<.01$ for all). The academic performance of the course was associated with increased publications ($P=.014$), whereas overall satisfaction of the course (OR 2.07, 95% CI [1.39, 3.10], $P<.001$), Skill Composite Score (SCS) (OR 1.70, 95% CI [1.16, 2.50], $P=.007$), and male gender (OR 1.50, 95% CI [1.06, 2.12], $P=.022$) were associated with increased future research interests.

Conclusions The findings suggest that the curriculum-based RTP improved students' research productivity, and that overall program satisfaction and self-assessed performance were associated with increased students' intent to participate in future research.

Keywords Curriculum-based research program, Research productivity, Research interests, Undergraduate medical education

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Introduction

Scholarly research training programs provide medical students with the opportunity to develop skills related to critically evaluating medical information, communicating and disseminating research findings, and contributing to the new discovery and innovation of medical knowledge [1–3]. These research experiences can foster evidence-based medical practice and bench-to-bedside translational research driven by physician-scientists [4, 5]. In order to support medical students in improving the research skills they will need in their future careers, a growing number of medical schools have incorporated research programs as core curriculum components in real research environments, either as mandatory, elective, or extracurricular activities [6–11].

Studies of research programs have employed various metrics to evaluate their effectiveness across different educational settings. Reviews of these initiatives indicate that involvement in structured research significantly boosts students' publication outputs and enhances their engagement in future research, with successful programs reporting higher academic productivity and a greater inclination towards research-oriented careers [1, 8, 9]. For instance, in the USA, programs at Duke University School of Medicine and Stanford University School of Medicine have long embedded rigorous scholarly activities into the curriculum, fostering advanced research skills and leadership qualities [6]. Similarly, Johns Hopkins has demonstrated increased research productivity through scholarly projects, as evidenced by publications and conference participation [12]. The University of Pittsburgh's initiative has cultivated critical analytical skills, leading to robust academic outcomes [13]. In the UK, research programs have been identified as a pivotal component of medical education, significantly enhancing student research skills and providing robust platforms for developing research-intensive careers [14, 15]. Meanwhile, in Sweden, a mandatory research course has positively influenced students' subsequent academic careers, encouraging many towards PhD studies and demonstrating the enduring impact of such programs [16].

However, despite the global adoption of research programs, students frequently encounter barriers such as insufficient time, inadequate support for basic research concepts from the curriculum, and a lack of acknowledgment and mentorship. These issues are common across both developed and developing countries [8, 10, 15, 17]. In developing regions, in particular, these challenges are compounded by the large number of students with no prior research experience and relatively insufficient teaching resources [8, 10, 17, 18].

On the need for evidence-based medicine and the increased demand for physician-scientists, medical schools in China have designed research courses and programs to encourage students to engage in research training [19, 20]. Currently, there were three types of educational programs in China's medical education system according to the duration of studies, 5-year programs (Bachelor), '5+3' integrated programs (Master), and 8-year Medical Doctor (MD) programs. Among them, the first two programs account for more than 98% matriculates each year, while only about 2% students come from the MD programs. Nevertheless, unlike 8-year programs that typically have intensive training programs, such as more advanced biomedical courses, systematic training in academic skills, and early assignment of research mentors, 5-year or '5+3' integrated programs occasionally have immersive research training due to a large number of students [19, 21]. The 2019 China Medical Student Survey (CMSS), which collected data from 33 medical schools in China, showed that more than half of students in 5-year programs had never participated in research activities, compared with only one in 10 students in 8-year programs [20]. The latest survey, which collected 113 medical schools in China in 2022, showed that the percentage is rising further (https://medu.bjmu.edu.cn), suggesting an urgent need for change.

As one of the leading medical schools in China, Zhejiang University School of Medicine (ZUSM) provides medical education for 5-year, '5+3', and 8-year programs. In 1998, ZUSM established a curriculum-based Research Training Program (RTP) specifically for 5-year and '5+3' program students, laying the groundwork for subsequent research training in the 8-year program [22]. Central to the RTP is the Stepwise Medical Student Research Training (SMSRT) course, which has utilized flipped classroom teaching since 2016. This course integrates basic medical experiments and independent research projects for 3rd-year students, emphasizing the development of critical research skills such as question formulation, data collection, rigorous analysis, and effective communication within a team setting. Following the mandatory SMSRT course, students can apply for a variety of elective longitudinal research programs that often lead to scholarly dissemination, such as peer-reviewed publications and presentations at regional or national meetings.

To date, ZUSM is one of the few medical institutions in China that offers intensive and rigorous research training for all medical undergraduates. Our curriculum-based research program combines the compulsory course and elective projects, which not only ensure formalized research experiences for a large number of students but also provide flexible in-depth research opportunities for students who are interested in research. The primary focus of this study is to explore the specific learning outcomes related to students' research productivity and their future research interests. These outcomes align with the core objectives of the RTP, which aims to enhance the

research capabilities and scholarly engagement of students. While other potential impacts such as research collaborations and clinical applications are also important, they fall beyond the main scope of this study. To guide our analysis, the research questions we aim to answer are: (1) How does participation in the RTP influence the research productivity of medical students? (2) What effect does participation in the RTP have on students' future research interests?

Methods

Research training program at ZUSM

RTP at ZUSM is a required component of the Bachelor of Medicine (BM) curriculum. It consists of a compulsory laboratory course (SMSRT) and an elective research project module (Fig. 1). As the core of the program, the SMSRT process occupies 128 curricular hours over a period of approximately 4 months for 3rd-year medical students. The first portion of this process was mainly designed using inquiry-based laboratory exercises each week to allow the students to practice for the upcoming independent project [23]. Students worked in small groups of three to complete the experiment, and 10 groups formed a class. After learning the foundations of medical research (principles of research design and methodology, basic statistics, research ethics, etc.) in the first week, students were required to complete four practical blocks (neurology and skeletal muscle, circulation, respiration, and urology), with 2 to 3 inquiry-based and problem-driven experiments in each block, ranging from basic experiments to comprehensive experiments. This series of weekly laboratory experiments expose students to the scientific research process, including method choosing, data collecting, statistical reasoning, and also professional skills, such as teamwork.

The latter half of the SMSRT process involved each class designing and implementing an independent novel research project under the direct supervision of a faculty mentor. As early as Week 2, students received lectures, discussion times, and readings about research skills. Each group in the class was asked to propose a research question and present a project proposal in Week 6. The research projects were typically hypothesis-driven, budget limited (15,000 to 20,000 CNY per class), and may include a variety of disciplines such as basic science, translational, and public health research. The class then voted for the most feasible research project, and students were required to design their own step-by-step research protocol together. The following five weeks (weeks 11–15) of class time are devoted entirely to the project, and students can also conduct data collection and analysis outside the normal class time limits. In the last week of the course, each student completed a formal thesis and orally presented their findings in groups. During the process of the project, the research mentor provided oral and written feedback to students on each individual or group assignment (project proposal, progress report, thesis, and oral presentation). Students were encouraged to present at conferences or prepare manuscripts for peer-reviewed journals, however, these were not mandatory requirements of the course.

After completing the course, RTP offers a variety of ways for students to further enrich their research experience: they may consider continuing their research projects with their course mentor or apply for the Student Research Training Program (SRTP) founded by Zhejiang University, or the provincial and national Undergraduate Training Program for Innovation and Entrepreneurship (UTPIE). These elective programs usually accept longitudinal projects that required ongoing participation by the student and include procedures such as

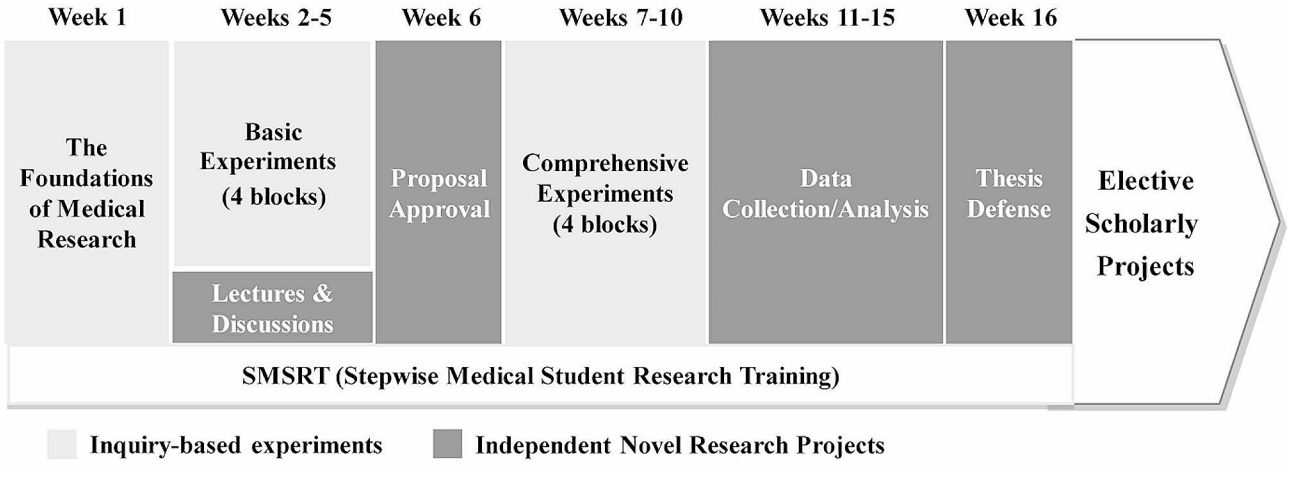

Fig. 1 Flow chart of the RTP structure at ZUSM

mid-term examination, final defense, and comprehensive assessments.

Study population and data collection

This cross-sectional observational study analyzed data from medical students who completed the SMSRT course of the RTP between September 2013 and January 2021. We included 2,213 students from both the 5-year and '5+3' programs in clinical medicine. Students enrolled in these programs undergo identical educational experiences during their first five years, participating in the same courses, adhering to the same academic standards, and fulfilling identical curriculum requirements. Eight-year MD program students were excluded.

In determining the metrics for evaluating the effectiveness of the RTP, we considered both international benchmarks and local educational objectives. The selection included metrics such as the number of publications in peer-reviewed journals and self-reported research interests, commonly utilized in medical education research to gauge scholarly productivity and student engagement [1, 9, 12, 16, 24]. In addition to these, we included academic metrics unique to our program, such as the Skill Composite Score (SCS) from course surveys and academic performance in the SMSRT course. These metrics were chosen to directly assess the RTP's impact on students' skills and academic success, aligning with our institution's goal of developing well-rounded medical professionals.

Program staff extracted data from the students' academic records and the RTP program's records. We gathered demographic data, including gender and grade point average (GPA) of students before they entered the SMSRT. The ZUSM undergraduate education office provided detailed information regarding the numbers of projects and team composition for students who participated in the SRTP and UTPIE programs. Scholarly productivity was measured based on the number of publications in peer-reviewed journals; this involved querying PubMed, EMBASE, and the China National Knowledge Infrastructure (CNKI) databases using students' names and our institution's name as search terms. To mitigate issues of name ambiguity, we compared the corresponding authors listed in the publications to faculty members at our institution. Additionally, we contacted faculty members directly to confirm the accuracy of the student authorship when ambiguities arose. We included articles published by students from July of their third year to July two years after graduation. It is important to note that abstracts presented at conferences or other scholarly meetings were not considered as publications. Only peer-reviewed articles in journals were counted as formal publications for the purposes of this research. However, at the time of analysis, published data from the Classes of 2017 and 2018 (completed the SMSRT course in 2019 and 2020) were thought to be too incomplete to be included in this part of our study. Additionally, students' self-reported data were collected via course surveys conducted at the end of the SMSRT in 2017 and 2018. The two surveys were selected for the following reasons: our first cohort using the survey described in this study completed the course in 2017, and students' publication data after 2019 are still incomplete. To ensure timely participation, students were reminded via campus text messages to submit their surveys. We also maintain a repository of email addresses for all participating students, which is accessed only with the course director's permission and in compliance with privacy regulations. All data were de-identified before analysis, and the study received approval from the Ethics Committee of Zhejiang University School of Medicine (IRB 2023-002).

Variable description and outcome measurement

In our study, we defined and measured seven primary outcomes based on Kirkpatrick's levels, ranging from satisfaction to behavioral change [1]. At the Reaction level, we evaluated students' overall satisfaction with the SMSRT course and their research mentors through a course survey, asking them to rate their satisfaction on a 5-point scale (5=very satisfied, 4=satisfied, 3=neutral, 2=not satisfied, 1=not at all satisfied). At the Learning level, we measured students' academic metrics, which included the self-reported SCS in the course survey and academic performance in the SMSRT course. The SCS was generated for each student by summing the 5-point scale responses (5=excellent, 4=good, 3=fair, 2=poor, 1=very poor) from five scores: develop a research question, critical appraisal of the medical literature, choose an appropriate research design, perform experiments correctly, and writing a scientific manuscript. Due to its non-normal distribution, the SCS was dichotomized at the median. Academic performance was divided into five groups (excellent=90 and above, good=80 to 89, average=70 to 79, fair=60 to 69, and poor=below 60). At the Behavior level, we defined scholarly productivity by the number of publications in peer-reviewed journals and assessed the application of longitudinal research projects and scholarly productivity throughout the RTP process. Additionally, to gauge changes in research interest, we asked students in the course survey, 'How has your interest in future research or academic work changed since your research training?'. Students responded on a 5-point scale: 5=increased a lot, 4=increased, 3=unchanged, 2=decreased, 1=decreased a lot.

Data analysis

We used descriptive statistics to summarize students' demographic characteristics as well as program

Table 1 Demographic and baseline academic characteristics of medical students who completed the scholarly research projects

Characteristic	2013	2014	2015	2016	2017	2018	2019	2020
Student, no.	222	214	295	290	333	318	250	291
Male, no. (%)	109 (49.1)	107 (50)	150 (50.8)	167 (57.6)	181 (54.4)	180 (56.6)	115 (46.0)	111 (38.1)
Female, no. (%)	113 (50.9)	107 (50)	145 (49.2)	123 (42.4)	152 (45.6)	138 (43.4)	135 (54.0)	180 (61.9)
GPA, mean (SD)	3.53 (0.53)	3.40 (0.63)	3.45 (0.57)	3.35 (0.68)	3.57 (0.68)	3.51 (0.70)	3.43 (0.71)	3.62 (0.68)

Table 2 Academic performance of SMSRT, research publications, and research projects of medical students[a]

Measure	2013	2014	2015	2016	2017	2018	2019	2020	*P* value
Academic performance, Median (95% CI)	82 (82, 83)	78 (77, 79)	83 (83, 84)	79 (78, 80)	85 (84, 86)	81.0 (80, 82)	82 (81, 83)	84 (83, 85)	**<.001**[b]
Number of publications, Median (95% CI), mean (SD)	0 (0, 0) 0.15 (0.38)	0 (0, 0) 0.18 (0.50)	0 (0, 0) 0.17 (0.45)	0 (0, 0) 0.34 (0.86)	0 (0, 0) 0.35 (0.73)	0 (0, 0) 0.42 (0.90)	n/a	n/a	**<.001**[b]
Students with publication, %	14.0	13.6	13.6	19.3	23.7	26.7	n/a	n/a	**.002**[c]
Students with first-authorship, %	5.9	2.8	4.4	6.6	4.8	8.2	n/a	n/a	0.320 [c]
Research projects, no.	68	70	64	65	72	70	93	84	n/a
Research projects (≥ 3 students per team), %	57.4	51.4	71.9	66.2	72.2	74.3	82.8	72.6	**<.001**[c]

[a]Published data after 2019 are not included because they are still incomplete

[b]*P* value determined by Kruskal-Wallis test

[c]*P* value determined by linear-by-linear test of trend

outcomes. For academic performance, research publications (numbers and proportions), and team composition of research projects, we assessed differences across years by the Kruskal-Wallis test, or by the linear-by-linear test of trend when an ordinal relationship seemed plausible for the temporal trends across years. Bonferroni correction was used for multiple analyses.

We divided students into two subgroups based on student publications or future research interests. The number of publications for each student was treated as a continuous variable. We then transformed it into dichotomous variables, comparing at least one publication with no publications. Students' future research interests were also transformed into a dichotomous variable, comparing high interest (increased a lot or increased) with low interest (unchanged, decreased, or decreased a lot). We investigated associations between the factors of interest (overall satisfaction, SCS, academic performance, and gender) and the publications or future research interests, and between various factors of interest, using Spearman rank correlation, Mann-Whitney *U* test, chi-square test, and nonparametric test of trend as appropriate. We further used logistic regression to describe the association of overall satisfaction, SCS, and gender with future research interests. All data analysis was performed using SPSS 26.0 (IBM Corp., Armonk, New York) with $P<.05$ defined as statistically significant.

Results

Demographics and academic characteristics

In total, 2,213 students completed the SMSRT course of RTP between 2013 and 2020. Table 1 presents the summary statistics on the demographic and academic characteristics of students. Of the 2,213 students, 1093 (49.4%) were female and 1120 (50.6%) were male. For academic variables, the mean and SD of the GPA before entering the SMSPT was 3.48±0.65. Prior to RTP, these students had similar demographics and baseline academic aptitudes.

Academic performance, research publications, and research projects across years

Table 2 summarizes students' academic performance in SMSRT, research publications, and research projects from 2013 to 2020. Although the academic performance of students varied significantly across the years, there was no ordinal relationship that seemed plausible for the temporal trends. For research publications, the number of publications for each student was significantly different across years ($P<.001$), with pairwise comparisons indicating a significantly higher number of publications in both 2017 and 2018 compared with 2013, 2014, and 2015 (Bonferroni adjusted P value for all comparisons <0.05). Similarly, the proportion of students with any publication increased across years ($P=.002$). However, there were no differences in the proportion of students with first authorship between years ($P=.320$). For longitudinal

research projects in the RTP process, since the number of projects each year is determined by the program organizer, we mainly analyzed the study field and team composition of the project. The majority of the students (75.0-90.8%) selected basic science, and only a few chose clinical/translational research (7.4–18.6%), public health (1.5–11.9%), and medical education (about 1.5%) (Supplementary Table 1). While there was little variation in the number of projects between years, there was a significant increase in projects involving three or more students ($P<.001$) (Table 2).

Effects on student publications or future research interests

In 2017 and 2018, 584 students returned the course survey at the end of SMSRT corresponding to a response rate of 89.7%. Most students were either satisfied (305; 52.2%) or very satisfied (210; 36.0%) with the course (very satisfied=5, not at all satisfied=1; Median 4, 95% CI [4]). Most students were either satisfied (222; 38.0%) or very satisfied (346; 59.2%) with their project mentor (very satisfied=5, not at all satisfied=1; Median 5, 95% CI [5]). Totally 305 (52.2%) students had high SCS, and 279 (47.8%) students had low SCS. Descriptive statistics for the five constituent scores of SCS are provided in Supplementary Table 2.

Table 3 describes the relationship between various factors of interest (overall satisfaction, SCS, academic performance, and gender) and the publications or future research interests. Supplementary Table 3 shows associations between factor variables. For student publications, it was only correlated with the academic performance of SMSRT ($P=.014$). Whereas for students' future research interests, three factors (overall satisfaction of the course, SCS, and gender) showed significant correlation or difference. We further conducted logistic regression and included these factors in the analysis model (Table 4). Our results showed that the more satisfied students were with the SMSRT course (OR 2.07, 95% CI [1.39, 3.10]), the higher the SCS score (OR 1.70, 95% CI [1.16, 2.50]), or male gender (OR 1.50, 95% CI [1.06, 2.12]), the more likely they were to be interested in future research.

Discussion

Reflecting on our research questions, this study at ZUSM provides insights into how structured research training programs like the RTP significantly influence medical students' research productivity and their future research interests. Our longitudinal data showed an increase in the number of student publications, a greater proportion of students with publications, and a greater proportion

Table 3 Descriptive statistics and association of study variables with students' publication and intent for career research

Characteristic	Publication		*P* value	Intent for career research		*P* value
	Yes	No		High	Low	
Overall satisfaction, no. (%)			.127[a]			**<.001[a]**
Very satisfied	48 (8.2)	162 (27.7)		144 (24.7)	66 (11.3)	
Satisfied	87 (14.9)	218 (37.3)		149 (25.5)	156 (26.7)	
Neutral	21 (3.6)	43 (7.4)		24 (4.1)	40 (6.8)	
Not satisfied	1 (0.2)	1 (0.2)		1 (0.2)	1 (0.2)	
Not at all satisfied	2 (0.3)	1 (0.2)		0	3 (0.5)	
Mentor satisfaction, no. (%)			0.259 [a]			0.142 [a]
Very satisfied	92 (15.8)	254 (43.5)		200 (34.2)	146 (25.0)	
Satisfied	60 (10.3)	162 (27.7)		111 (19.0)	111 (19.0)	
Neutral	6 (1.0)	9 (1.5)		7 (1.2)	8 (1.4)	
Not satisfied	0	0		0	0	
Not at all satisfied	1 (0.2)	0		0	1 (0.2)	
SCS, no. (%)			.711[b]			**<.001[b]**
High	81 (13.9)	224 (38.4)		193 (33.0)	112 (19.2)	
Low	78 (13.4)	201 (34.4)		125 (21.4)	154 (26.4)	
Academic performance, no. (%)			**.014[a]**			0.538 [a]
Excellent	10 (1.7)	21 (3.6)		16 (2.7)	15 (2.6)	
Good	125 (21.4)	285 (48.8)		231 (39.6)	179 (30.7)	
Average	22 (3.8)	111 (19.0)		66 (11.3)	67 (11.5)	
Fair	2 (0.3)	7 (1.2)		5 (0.9)	4 (0.7)	
Poor	0	1 (0.2)		0	1 (0.2)	
Gender, no. (%)			0.402 [b]			**.020[b]**
Female	79 (13.5)	193 (33.0)		134 (22.9)	138 (23.6)	
Male	80 (13.7)	232 (39.7)		184 (31.5)	128 (21.9)	

[a] *P* value determined by linear-by-linear test of trend

[b] *P* value determined by Chi-square test

Table 4 Logistic regressions of students' intent for career research

Characteristic	OR	95% CI	*P* value
Overall satisfaction	2.07	1.39, 3.10	**< 0.001**
Mentor satisfaction	0.89	0.60, 1.31	0.551
SCS	1.70	1.16, 2.50	**0.007**
Academic performance	1.35	0.90, 2.02	0.143
Male gender	1.50	1.06, 2.12	**0.022**
Publication	0.98	0.67, 1.44	0.936

of projects involving three or more students across years, especially after the flipped teaching-based curricular reform in 2016. We also tracked Kirkpatrick's educational outcome variables at various levels, from satisfaction to behavioral change, to particularly highlight how the RTP influences student publications and their future research interests. The academic performance of the SMSRT process was associated with increased publications, whereas overall satisfaction of the course, SCS, and male gender were associated with increased interest in future research.

Among the student outcomes that research programs usually measure, peer-reviewed journal publications are generally considered as an indicator of research productivity, reflecting students' ability to apply acquired knowledge and skills to a career setting [1, 25]. It has been reported that the publication rate of students who had participated in scholarly programs varies greatly. For example, earlier reports showed that 8–85% of the medical students had published at least one paper after their research period [1]. An international cohort study found that 8.9–75.7% medical students from six different countries had articles accepted or published in journals [17]. In contrast to the relatively high proportion of students in many western countries who have participated in scientific research activities before scholarly research programs, most Chinese students have no prior research experience before enrollment. This makes formal and rigorous research training particularly important for medical students in China. With the help of RTP in ZUSM, the proportion of students with publication reached to 26.7%. Furthermore, the number of peer-reviewed manuscripts published by ZUSM students increased across the years, which is higher than the average level of medical schools in China according to the national CMSS survey in 2022 (0.42 of ZUSM vs. 0.17 of CMSS) (https://medu.bjmu.edu.cn).

We believe that several factors have influenced the increase in research productivity over the decade at ZUSM. First, compared to more than half of students in 5-year programs who had never participated in research activities in medical schools in China [20], ZUSM provides all students with the opportunity to perform research in the SMSRT process, and more than 60% of students also participate in longitudinal research programs during the rest of the RTP. Also, we adopt inquiry-based and problem-driven laboratory exercises in SMSRT since 2016, which have been demonstrated to allow students to practice the scientific process and develop key competencies of scientific research [26, 27]. Through the stepwise procedure, students could be well prepared for the latter independent novel research project in SMSRT, then finally the authentic longitudinal programs in RTP. ZUSM also has a group of faculty who now have more experience working with medical students on the RTP and may be more effective in mentoring students in the program. Lastly, ZUSM is one of the top research-focused medical schools in China and may attract students who are more interested in research upon matriculation. However, since the intended outcomes of our RTP are mainly focused on the research process and methodology itself, that could be a hindering factor to student publication frequency. Starting with the class of 2019, ZUSM requires all medical students to complete an academic paper before graduation, which may bolster the number of student publications.

We also analyzed students' application of elective longitudinal research projects in the RTP process and found a significant increase in projects involving three or more students. It should be noted that in addition to research-specific skills, interpersonal skills, such as teamwork and communication skills, are also considered important core competencies for medical practitioners [14]. An essential feature of our curriculum-based research program is the cultivation of teamwork. Because of the multifaceted nature of the SMSRT project, students must work together to complete every part of the project from design to presentation, therefore helping them develop desirable skills in a collaborative environment. Another finding was that most students in this study preferred basic science investigation over other research fields (e.g. clinical/translational research, public health, and medical education). It has been reported that translational and clinical research experiences have become increasingly attractive alternatives for many medical students [6]. Whether our findings are the real choice of ZUSM medical students or due to the imbalance of relevant resources in RTP (e.g. shortage of clinical mentors) warrants further study.

When exploring the potential factors that contribute to the student publication, only the academic performance of the SMSRT process was associated with increased publications. This finding is consistent with the national CMSS survey analysis that medical students with better academic performance in China are more likely to engage in research, which may lead to more learning outcomes [20]. On the other hand, it has been reported that medical school research experience was associated with increased interest in research or academic activities after completion of training [1, 12, 24]. In the present study, we found that specific variables including overall satisfaction of the course, self-reported skill scores, and gender may lead to this increased interest. Among these variables, previous studies have shown that program satisfaction is associated with increased intent to pursue career-long research, with two of the potential contributors being quality mentorship and improved student research self-efficacy [12, 24]. The supervisors' experience and availability to students are often considered as key factors of student career paths and interest in academic medicine [28]. The support from supervisors (or mentors) is expected to include practical guidance, supervision, and feedback designed to promote deeper understanding and the development of autonomy. Further understanding of factors influencing mentor satisfaction, including project success, the mentor's experience and practice, and the specific skills taught by the mentor, may enhance understanding of the mentor's contribution to overall satisfaction. For another potential contributor, student research self-efficacy, we collected students' self-assessed performance in the five core competencies of the course (i.e. SCS) and identified a positive correlation between SCS and future research interests. Self-efficacy refers to a person's belief in their ability to achieve a certain goal [29]. Participation in research projects has been shown to improve research self-efficacy among medical students [12, 30]. Accordingly, a systematic review examined the perceptions of medical students regarding research revealed that students who lacked the relevant research skills may result in low motivation and a lack of self-efficacy [10].

Regarding gender disparity, we found a significant difference in future research interests between male and female students. More male students expressed interest in research participation in the future. Interestingly, several studies have shown that women's self-efficacy and interests tend to be lower in research fields as compared to men [31–33]. The national CMSS survey analysis also shows that male medical students in China benefit more concerning the Science and Scholarship domain of learning outcomes [20]. However, considering that the other two factors identified in this study (overall satisfaction and skill scores) that were associated with increased research interests remained the same between men and women, the reasons behind this phenomenon need further investigations in future studies.

Transitioning from the internal dynamics of the RTP, it is important to address how such programs can be adapted to institutions with varying resources. Our experience suggests that structured, inquiry-based laboratory exercises and an emphasis on mentorship form the core of RTP's success. For resource-constrained settings, prioritizing digital tools and collaborative platforms could mitigate some of the physical resource requirements, enhancing the program's scalability and adaptability. Furthermore, innovative solutions like the flipped classroom model and peer mentorship have proven effective in our setting to maximize resource utilization and tackle common challenges such as mentor scarcity and time constraints. These strategies could potentially be adapted to different educational environments, offering a versatile framework for enhancing research training globally.

To further evaluate the relevance and applicability of our findings on a global scale, it is instructive to consider similar research training programs internationally. Medical schools in countries such as the United States and Europe often feature extensive research training tracks, which may include dual-degree programs like MD-PhD, reflecting a robust integration of research into medical education [6, 15]. These programs are designed not only to enhance research skills but also to promote a seamless transition into academic medicine. Comparing the RTP at ZUSM with these international models highlights significant structural and resource-related differences but also underscores common objectives in enhancing research competencies [8, 9]. Despite varying resources, ZUSM has demonstrated that structured programs can significantly boost research outputs and engage students effectively, serving as a potential model for similar institutions facing resource constraints. Such international comparisons not only affirm the universality of enhancing medical student research capabilities but also pave the way for collaborative adaptations that could be beneficial across different educational systems and resource settings.

Limitations

One limitation of the current study is that we conducted it at a single institution in China that is research-oriented and where many students wish to pursue subspecialties and academic careers. Therefore, our results might differ from those of other medical schools in China with more limited research and academic goals. In addition, this study does not encompass long-term outcomes such as impacts on participants' choices of clinical specialty or direct improvements in patient health, which are crucial aspects within the Results level of Kirkpatrick's

model as outlined by Bierer S.B. et al. [1]. The absence of comprehensive post-training data restricts our ability to evaluate these advanced impacts. Recognizing this limitation, future research should aim to gather longitudinal data that can assess the enduring effects of the RTP on academic medicine careers, clinical practice improvements, and broader organizational or societal contributions. Such follow-up studies might include analyses of sustained research engagement, publications post-graduation, and academic appointments obtained after residency training. Besides, as a required course, we do not have data on students who have not completed the RTP program. Lastly, the survey used in this study included graduates from only two grades and the question of future research interests was only queried post-program which might introduce recall bias. More students and changes in research interest from pre-program to post-program should be included in further studies.

Conclusions

This study provides evidence of the learning outcomes of the curriculum-based RTP at ZUSM. The proportion of students with peer-reviewed publications has consistently increased over the years, clearly demonstrating an improvement in students' research productivity, a primary focus of our research questions. Moreover, findings indicate that program satisfaction and students' self-assessed performance are positively associated with increased intent to participate in future research, underscoring the RTP's role in fostering long-term research engagement among students. Overall, the curriculum-based RTP offers rigorous and authentic research experiences for a large number of students, and can serve as a model for other medical schools interested in developing similar programs to bolster the physician-scientist workforce.

Abbreviations

RTP	Research training program
SMSRT	Stepwise medical student research training
SRTP	Student research training program
UTPIE	Undergraduate training program for innovation and entrepreneurship
SCS	Skill composite score

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12909-024-05841-0.

Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

Acknowledgements

The authors would like to thank the students at Zhejiang University School of Medicine for their engagement in this course. The authors would also like to acknowledge the faculty and staff of this course and the Undergraduate Education Office of Zhejiang University School of Medicine for their support. We further extend our gratitude to all who assisted in adhering to the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines; the STROBE checklist is included as Additional File 3 to enhance the transparency and reporting of our study.

Author contributions

JS contributed to the study design, data analysis, and drafting of the manuscript. JS, HQ and GL contributed to data collection, data analysis, and critical review of the manuscript. XL and YF contributed to data collection. All authors have read and approved the final manuscript.

Funding

This work was supported by the Zhejiang Province "14th Five-Year" Teaching Reform Research Project (jg20220038); and the Zhejiang University School of Medicine High-level Education and Teaching Achievement Award Cultivation Project (cgyb20192001).

Data availability

Datasets that support the conclusions of this study are included in the article. Additional data at the individual student level are not publicly available because of potential risks to student privacy, but are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

This study was approved by the Ethics Committee of Zhejiang University School of Medicine (IRB 2023-002). Informed consent was obtained from the participants prior to participation in this study. All procedures in this study was carried out in accordance with the Declaration of Helsinki.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Received: 27 May 2023 / Accepted: 30 July 2024
Published online: 02 August 2024

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