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Faculty members' perceptions and students' experiences of research-based curricula: a multiple case study of four undergraduate programmes

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Abstract
The implementation of a research-based curriculum that enables students to develop essential capabilities for this complex world is challenging. There is limited understanding of the implementation of a research-based curriculum in a whole degree programme, and few studies examined how faculty members and students perceived such a curriculum. This study explored faculty members' perceptions and students' experiences of four research-based curricula in two research-intensive universities in Hong Kong. Based on document review, 18 faculty interviews, and 113 student interviews, we discovered an overall positive view of research-based curricula but also substantial differences between faculty members' perceptions and students' experiences. For example, faculty members emphasised the learning and critical evaluation of knowledge. In comparison, students focused on exploring specific interesting issues and collecting and analysing information without fully recognising the potential of research in generating, applying, and validating knowledge. Moreover, students' experiences of research-based curricula contained a broader scope of activities than the curriculum perceived by faculty members. These gaps demonstrate that the fundamental goals of research-based curricula to develop 'powerful knowledge' and induct students into disciplinary ways of thinking have yet to be fully achieved. The study implies a need to enhance communication between students and faculty members and build a consensus on designing and supporting undergraduate research across the curriculum.

Keywords Research-based curriculum · Undergraduate research · Research-based learning · research-teaching nexus · Case study

Introduction

Undergraduate education needs to prepare students for the unpredictable future in a changing world (Pattison et al., 2022). In the recent two decades, Hong Kong's tertiary education has been undergoing a transition from teacher-centred to student-centred learning. A

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report published in 2000 stated that university students were not given 'comprehensive learning experiences with little room to think, explore and create' (Hong Kong Education Commission, 2000, p.4). Research-based learning was introduced to engage students more actively in the learning process (UGC, 2010). Universities in Hong Kong were also recommended to form strategies for 'bringing research into the classroom… and involving undergraduate students in research projects' (UGC, 2010, p.84).

In this context, a research-based curriculum has been established as an impactful design that develops undergraduates' capabilities for coping with ambiguities and uncertainties (Brew, 2013). Carnell and Fung (2017) define research-based learning as students conducting research and inquiry-based activities in which they exercise agency, develop research skills, and acquire a critical understanding of knowledge. A research-based curriculum is a curriculum that is primarily designed around research and inquiry-based activities instead of subject content delivered to students (Griffiths, 2004).

A research-based curriculum enables the development of 'powerful knowledge' that students can apply across contexts (Harland & Wald, 2018; Young, 2009) as well as critical thinking skills—the foundational skills that enable them to evaluate any knowledge claims (Harland & Wald, 2018). To develop an effective research-based undergraduate curriculum, scholars argue that research capacities must be built over a programme coherently (Hughes, 2019). Having a capstone in the final year is insufficient; instead, research opportunities should be built into the curriculum to create a research 'throughline' (Fung, 2017).

However, translating these principles into curriculum design presents challenges. Faculty members' perceptions of undergraduate research vary, with some perceiving almost everything students do as research versus others only recognising certain activities (Brew & Mantai, 2017). Some faculty members argue that undergraduates have not yet reached the suitable level for conducting research and that some simply do not enjoy developing research skills (Brew & Mantai, 2017). Students' experiences of research-based learning also vary, with some developing a sense of what research is in the early years of their study and others perceiving research as a distant task (Robertson & Blackler, 2006). One key aspect of undergraduate research is the effectiveness of mentoring, which involves faculty members balancing between monitoring students' work and giving them the freedom to experience as student researchers (Walkington et al., 2020). Therefore, examining students' and faculty members' perceptions or experiences in the same setting might provide useful insights into curriculum design and mentoring. There is currently a lack of a holistic view of the curriculum among teachers and students (Wijngaards-de Meij & Merx, 2018), making it difficult to appreciate the integration of research across the curriculum.

Thus, there is a gap between the rhetoric of a research-based curriculum and practice. This study set out to examine the integration of research-based learning across an undergraduate degree programme, an area that has not yet been fully explored. We solicited both teachers' and students' views across disciplines. A multiple case study method was adopted to examine four undergraduate degree programmes comprising one pure science discipline, two applied science disciplines, and an interdisciplinary programme that integrates arts, social sciences, and science. Curricular documents were reviewed, followed by 18 faculty interviews and 113 student interviews. The findings show different conceptualisations of a research-based curriculum and a 'throughline' between faculty members and students. We argue that communication of intentions and assumptions about the expected outcomes of research-based curricula to both teachers and students is important for effective implementation, and that if it is desired to achieve a 'throughline' from novice to experienced researcher, this must be made clear to all who engage in the programme.

Literature review

Research-based curricula and a 'throughline'

Numerous studies show the benefits of a research-based curriculum (e.g. Barnett, 2000; Brew, 2013; Spronken-Smith et al., 2011; Walkington & Ommering, 2022). Drawing on Steinberg and Kincheloe (1998), Brew (2013) argues that an effective education should allow students to take part in knowledge production, evaluation, and dissemination. Theoretically, a research-based curriculum provides undergraduates with epistemic access to disciplinary ways of thinking (Shanahan et al., 2015) and enables them to learn 'powerful knowledge' that is specialised and can be applied across contexts (Harland & Wald, 2018; Young, 2009).

Extensive research has been conducted on specific undergraduate research components, for example, capstones (Moore et al., 2018) and research seminars (Pickenpaugh et al., 2022), but few studies examine research experiences throughout the programme. An effective research-based curriculum offers a guided research journey as a 'throughline':

> Each programme of study needs to be designed in such a way that students experience a connected sequence of learning activities that empower them, step by step, to apply the skills and dispositions needed to undertake investigations. (Fung, 2017, p.6)

In principle, a 'throughline' can take various forms. Examples include multiple modules requiring students to conduct research activities over several years and a core assessment such as a portfolio that connects various courses (Fung, 2017). Hughes (2019) suggests a throughline needs to be made visible to students so that they will understand the purpose of undertaking research. Similarly, Walkington and Ommering (2022) found significant benefits to undergraduates' well-being when they are engaged in a full research process within the curriculum comprising authentic problems, high-level autonomy, mentoring and support, and dissemination of research findings.

Research-based curricula in implementation

Implementing research-based curricula with a 'throughline' in a degree programme is not straightforward, with only a few successful cases reported. One concerns an ecology degree programme at the University of Otago. Its 'throughline' allows students to undertake structured research at the earlier stage and open inquiry in capstones at a later stage (Spronken-Smith et al., 2011). Similar designs can be found in a social science programme in a UK university, in which students go through tightly structured research activities in the first year, proceed to more autonomous inquiries in the second year, and finally pursue self-directed research (Rand, 2016).

Since there is no consensus on a research-based curriculum, we draw on the aforementioned examples to draft a working definition comprising the following features:

- It engages students in multiple, interconnected research activities across the curriculum as an integral part of the programme.
- It provides students with opportunities to participate in knowledge production, evaluation, and dissemination using disciplinary or interdisciplinary methods.

- It trains students to be critical thinkers and autonomous researchers through progressive development from earlier years to graduation.

Regarding research activities, we refer to the definition provided by the Council on Undergraduate Research (2021, n.p.): 'A mentored investigation or creative inquiry conducted by undergraduates that seeks to make a scholarly or artistic contribution to knowledge'. This definition recognises that undergraduate research contains various types of projects and processes and emphasises the importance of mentoring. Accordingly, examples of undergraduate research in our study include identifying gaps in the literature (for all disciplines), formulating hypotheses and designing experiments to address an emerging problem (in the pure science discipline), investigating a new property site or creating a nutrition plan using research methods (in the applied science disciplines), and adopting an interdisciplinary lens to study a phenomenon (in the interdisciplinary programme). In addition, undergraduate research can be undertaken in various forms, for example, collaboratively or individually, and on campus or in the community (Beckman & Hensel, 2009).

We are aware of the limitations of the above definitions. First, they have not fully considered disciplinary differences and nuances in research. Faculty members seldom have a consensus on the research themes within a discipline, leading to difficulties in curriculum design (Hughes, 2019). Second, research contains iterative processes, which might not be neatly captured by a 'throughline' (Rand, 2016). Third, many faculty members have a high level of autonomy in course design, and it might be too ideal to assume that coherence can be achieved across multiple courses (cf. Zou et al., 2023). Fourth, the wide variety of research activities in the current definitions means that it takes considerable effort to meaningfully connect these activities.

The conceptual limitations add to the complexities of implementing research-based curricula. Many trade-offs between what ideally needs to be included in the curriculum and what can be practically included are found (Welch & Panelli, 2003). Hughes's (2019) research in a UK-based university that implements research-based curricula found programme leaders had difficulty articulating the research skills expected to be developed in their programmes. Additionally, many faculty members are not fully prepared to support undergraduate research (Hughes, 2019).

There is also a lack of research on how students experience research-based curricula in the entire programme. One exception is Clark and Hordosy (2019) that trace students' experiences over the years and find that when there is insufficient scaffolding or when the research activities do not connect with students' interests, students do not appreciate doing research (Clark & Hordosy, 2019). Based on a survey conducted in four US institutions, Mahatmya et al. (2017) identified that students' perceptions (e.g. not being ready for research and lacking time) are significant barriers to their participation in research. Zou et al. (2022) suggest that undergraduates in Hong Kong value research experiences directly useful to their career development while paying less attention to basic activities, such as literature review and data analysis.

Research-based curricula in disciplinary contexts

A research-based curriculum assumes that student learning 'should reflect the kinds of active, critical and analytic enquiry undertaken by researchers' (Fung, 2017, p.20). Thus, faculty members will have to engage students in disciplinary ways of thinking (Walkington & Ommering, 2022). However, teaching and research are often practised as separate

activities (Brew, 2010). Even worse, teaching is sometimes perceived as 'a generic activity that lies *on top of* the *real* academic work, namely research' (Jawitz, 2009, p.242, emphasis in original).

Disciplinary variations in terms of integrating research with teaching have been discussed. One way to distinguish between disciplines is to examine the degree to which there is a consensus about paradigms, referred to as 'theories, methodologies, techniques, and problems addressed within a discipline' (Colbeck, 1998, p.651). 'Hard' disciplines such as physics and chemistry are often associated with a higher paradigm consensus, with knowledge perceived as cumulative and universal (Becher, 1989). In contrast, 'soft' disciplines such as humanities and social sciences are associated with a low paradigm consensus, with knowledge perceived as particular and qualitative (Becher, 1989).

Colbeck (1998) suggests that it is difficult to integrate research into teaching in hard disciplines because faculty members are working on frontier research, while undergraduates' research is at a basic level. Similarly, Robertson (2007) found weaker relations between teaching and research in science disciplines and stronger relations in humanities. From a curriculum perspective, Levy and Petrulis (2012) state that a low paradigm consensus offers more space for open-ended inquiries to be embedded in the early years.

Some disciplines, such as ecology, share features of both 'hard' and 'soft' disciplines. Harland and Wald (2018) suggest that research capacity development in ecology programmes can take place alongside the learning of basic theories, and students develop 'powerful knowledge' as they participate in knowledge production through research and acquire disciplinary styles of thinking.

Methodology

Research design

This study aims to examine research-based curricula and explore a 'throughline' concept in four undergraduate degree programmes based in two research-intensive universities. The study was guided by the following research questions:

1) How is research-based learning integrated across the curriculum in four undergraduate programmes in pure science, applied science, and interdisciplinary arenas?
2) How do faculty members and students perceive/experience research-based curricula and a research 'throughline'?

This study was positioned in an interpretivist paradigm with the aim of exploring how teachers and students interpreted the situations. Given the limitations identified in the current definition of research-based curricula, we remained open to revisions to this definition. We also follow the argument that any research on curricula is complex (Harden, 2001). Harden (2001) suggests there are three 'versions' of a curriculum: the declared (i.e. written in the documents), the taught (i.e. delivered by faculty members), and the learned (i.e. experienced by students). We expect that there would be similarities and differences between these versions of the curriculum.

A multiple case study approach was adopted (Merriam, 1998), with each case representing a four-year undergraduate programme leading to the award of a bachelor's degree with honours classifications. Four cases were examined: one in pure science, one in applied

science, another also in applied science but with a strong professional orientation, and one being interdisciplinary. These programmes were selected purposefully as they all involved an intentional plan to integrate research into the curriculum. The pure science and the interdisciplinary programmes were relatively new, and they were designed with research-based learning being the main feature. The two applied science programmes experienced recent restructuring to enhance their research-based learning. Involving three science curricula helps respond to the challenges reported in the literature regarding integrating research with teaching in hard disciplines.

We also acknowledge that our research design and analysis of the data and subsequent findings arise from our interpretations as researchers. These are subject to our biases derived from the positions we occupy as university teachers and researchers interested in the development of research-based curricula.

Context of the study

The four cases were located in two publicly funded research-intensive universities in Hong Kong, in which research-based learning is a key feature of their undergraduate curriculum. Both universities were ranked within the first one hundred in several world university rankings (e.g. Times Higher Education and QS Ranking). The vast majority of faculty members in the two universities had a doctoral degree, and many graduated from reputable universities outside Hong Kong. The two universities attracted high-calibre students within and beyond Hong Kong.

Data collection

In each case, data were collected from curricular documents (i.e. documents detailing all courses students needed to take) and teacher and student interviews (see Table 1). Regarding document review, the focus was on the programme objectives and curriculum design. We also reviewed intended learning outcomes, activities, and assessments of key research components—courses featuring research-based learning (e.g. research method courses and capstones). Attention was paid to how a research 'throughline' was constructed.

Faculty members who taught key research components identified in the documents were invited to attend semi-structured one-on-one interviews. Twenty-four invitations were sent, and 18 faculty members accepted the invitation. Half of the interviewees identified as early-career faculty members, and the other half identified as senior members. Interview questions focused on the research-based learning design in their courses as well as how

Table 1 Student and teacher interviews in each case

Case	No. of teacher interviews	No. of student interviews
Case 1—Applied science	5	30
Case 2—Pure science	3	16
Case 3—Applied science (professional oriented)	6	38
Case 4—Interdisciplinary	4	29
Total	18	113

those courses were positioned in the curriculum. Interviewees were also asked to comment on whether they perceived a research 'throughline' and how that 'throughline', if any, affected student learning.

Following a purposeful sampling framework and a maximum variation principle (Patton, 2002), we recruited students from different years (i.e. first and second years: 37; third year and above: 73; not specified: 3). The 113 interviewees represented 13.1% of the total student population in the four programmes involved. Questions for students focused on their experience of undertaking research-based learning across the curriculum. Students were also invited to comment on their progression throughout the study.

Student interviews were conducted by 13 trained student co-researchers, who were recruited from the programmes under study. These student co-researchers attended the interview training, received feedback from the first author, and commented on the interview questions based on their 'insider' perspectives. For example, some suggested terminologies in the interview protocol (e.g. 'research project' instead of 'undergraduate research'; 'useful' instead of 'conducive to') that would be better understood by students. Student co-researchers also generated probing questions. One example was 'What about the … course? There was a research project. I wonder if you took it?'

All the interviews were conducted in English, the medium of instruction in both universities. Each teacher and student interview took approximately 50 and 35 minutes, respectively. Ethics approval was obtained from the university where the first author was based (SBRE-21-0297). All participants, including faculty members, students, and student co-researchers, signed the consent form. Student co-researchers were paid on an hourly basis, and they were informed that they could withdraw from the study at any time, while their working hours would be remunerated no matter when they withdrew.

Data analysis

Within each case, curricular documents were analysed using content analysis to identify research learning opportunities. Teacher and student interview transcripts were analysed thematically following Braun and Clarke (2021). Initial codes were assigned to small text segments and then compared and grouped according to their similarities. Themes were identified that summarised one or more clusters of codes. The themes generated from the transcripts within each case were compared and contrasted. Finally, themes were refined or combined.

The cross-case analysis then included comparing the findings from individual cases. A brief summary of the findings was sent to the programme director of each case to seek comments. All the four programme directors provided written comments, which were analysed thematically in a similar manner as the interview data.

Findings

The following sub-sections present findings. Tables 2, 3, and 4 summarise the faculty members' interpretations and student experiences and show the number of interviewees expressing particular views. The percentages indicate the proportion of faculty members and students to the total number of faculty members and students interviewed. The factors associated with positive designs/experiences and those with negative ones are presented in Tables 3 and 4.

Table 2 Perceptions/experiences of the research-based curricula

Perceptions/experiences	Number of faculty members (percentage)	Number of students (percentage)
A curriculum that helps students learn and critically evaluate academic knowledge	18 (100.0%)	12(10.6%)
A curriculum that requires applying theories to tackle real-world problems	15 (83.3%)	21(18.6%)
A curriculum that offers a taste of the disciplinary research culture	15 (83.3%)	3 (2.7%)
A curriculum that facilitates students making contributions to the community	10 (55.6%)	38 (33.6%)
A curriculum that involves students generating new knowledge and original contributions to the research field	6 (33.3%)	11 (9.7%)
A curriculum that focuses on learning research methodologies and techniques	5 (27.8%)	27 (23.9%)
A curriculum that requires collecting and analysing information to make a conclusion	-	44 (38.9%)
A curriculum that facilitates exploring something interesting	-	28 (24.8%)

Table 3 Factors contributing to positive designs/experiences of the research-based curricula

Factors	Number of faculty members (percentage)	Number of students (percentage)
Providing/receiving specific support	17 (94.4%)	88 (77.9%)
Creating open-ended research opportunities/having sufficient autonomy in designing and conducting research	16 (88.9%)	20 (17.7%)
Exposing students to research earlier in the curriculum	13 (72.2%)	10 (8.8%)
Generating enthusiasm for research among students/exploring something exciting or with personal relevance	10 (55.6%)	40 (35.4%)
Faculty members acting as role models/learning from faculty members' own research	5 (27.8%)	15 (13.3%)
Providing/having a full-cycle research experience	4 (22.2%)	42 (37.2%)
Opportunities to learn professional skills (e.g. communication, teamwork, time management)	-	23 (20.4%)
Opportunities to collaborate with peers	-	23 (20.4%)
Opportunities to be creative (e.g. using new methodologies)	-	3 (2.7%)

Table 4 Factors contributing to negative designs/experiences of the research-based curricula

Factors	Number of faculty members (percentage)	Number of students (percentage)
Incoherent designs of research opportunities among different courses/the curriculum being incoherent	2 (11.1%)	2 (1.8%)
Stress and confusion caused by flexibility in the curriculum	-	33 (29.2%)
Lacking specific support	-	26 (23.0%)
Lacking autonomy in designing and conducting research	-	8 (7.1%)
Not having a full-cycle research process	-	4 (3.5%)
Not matching one's interest	-	4 (3.5%)
Lacking opportunities to learn practical applications of theories	-	4 (3.5%)
Not being confident in conducting research	-	2 (1.8%)
Preferring to receive knowledge directly rather than through research	-	2 (1.8%)
Aiming to pursue good grades (seen as inconsistent with conducting research)	-	2 (1.8%)

The research-based curriculum conceptualised in documents

In all cases, our working definition of research-based curricula was to a large extent reflected in the documents. First, each curriculum contained multiple, interconnected research activities as an integral part of the programme. Research-based learning was featured in the learning outcomes and the programme design. Each programme had multiple research courses in the first three years of study and a capstone in the final year. Second, the programmes provided opportunities for knowledge production, evaluation, and dissemination using disciplinary or interdisciplinary methods. Third, all the programmes emphasised the development of critical thinking skills and integration of theory and practice, and the curricula design showed a potential for progression from basic inquiries to more complex research.

Each programme had specific features. Specifically, Case 1 (applied science) had a learning outcome stating that students needed to 'apply independent thinking and the principles of scientific enquiry to conduct a small research project'. The courses were categorised into three blocks: introductory courses, advanced courses, and a capstone, implying progressive development from acquiring foundational knowledge and skills to completing research projects. Furthermore, students can choose between a primary science major and an intensive one; the latter will require the completion of eight to nine more courses containing advanced research elements.

Case 2 (pure science) was designed for students interested in pursuing a research career or enriching research experiences. The syllabus listed milestones of research capacity development over the four years, namely, exposures to scientific research, literature reviews, topic formulation, and, finally, completion of a research project. A unique aspect of Case 2 was an international research internship between the third and the fourth year, during which students worked in a renowned laboratory overseas.

Case 3 (applied science, professional-oriented) focused on developing students into professionals with critical inquiry and problem-solving capabilities. Information about professional accreditation is also included in the documents. Research method courses are

compulsory in the third year, preparing students to undertake the dissertation course in the final year. A unique aspect of Case 3 was a series of studio-based courses starting from the second year to the final year, which is built around the professional life cycle of the discipline.

Case 4 (interdisciplinary) emphasised personalised learning, holistic development, and students' capabilities to integrate different disciplines in order to tackle such challenges as climate change and inequality. Students needed to take qualitative and quantitative research methods courses in their first two years before pursuing their own research questions. At a certain point, when students feel ready, they could opt to declare a topic area of interest and subsequently build courses around that area.

The research-based curriculum perceived by faculty members

The research-based curricula were perceived by faculty members as an effective curricular design that facilitates the acquisition of knowledge and development of critical thinking skills. The most frequently discussed rationale for implementing the curriculum was to enable students to acquire, apply, and evaluate knowledge in a scientific manner. For example,

> What I want students to understand is what information is credible. Instead of thinking all that on social media or random web pages is credible, students need to learn knowledge in a proper way, reading research papers and carefully evaluating the worth of knowledge. (Case 1, senior)

The other frequently mentioned perceptions were applying theories to tackle real-world problems (83.3%) and offering a taste of disciplinary culture (83.3%), followed by making contributions to the local community of which the university was part (55.6%).

In most interviews, research was seen as more of a learning pedagogy than a process of knowledge generation, although 33.3 percent of the interviewees suggested that undergraduate research could make original contributions to the field. For example,

> Undergraduates often apply existing methods to solve new problems, thereby making new contributions…. Hong Kong's context is unique, and students often choose to work on the most recent challenges. Their research can definitely be original. (Case 3, early-career)

When asked about what made an effective research-based curriculum, the frequently mentioned factors included providing students with specific support (94.4%), creating open-ended problems with sufficient opportunities to explore (88.9%), and exposing students to research earlier in the curriculum (77.2%). The only negative factor mentioned was occasional inconsistencies in the research agenda between different courses taught by different faculty members across the curriculum (11.1%).

All faculty interviewees were aware of research-based learning being a curricular feature, but not all offered views on how different components were connected to facilitate progressive development. Among the 18 faculty interviewees, nine discussed a research 'throughline', referring to the organisation of research components that develop students' research capabilities from early years to graduation. A typical way of describing the 'throughline' was to highlight research components at each year of study:

> Students need to undertake important research work from the first year to graduation. In Year 1, there are 20 to 30 research seminars on different topics…. In Year 2, they

> will conduct literature review…. In Year 3, they write research proposals, formulate objectives, do lab work, and carry out preliminary work. Between the third and the fourth year, there is an international internship. In their final year, students execute the research project in full. (Case 2, senior)

Faculty members in Cases 1 and 2 described a similar progression from knowing about the research field and the foundational principles, to literature reviews, to the formulation of research proposals, and finally execution of a capstone. Faculty members in Case 3 emphasised a close connection between students' research experiences and the professional lifecycle. The level of difficulties in research also increased gradually:

> We basically follow the lifecycle of property development. Altogether, there are six courses in this series. Initially, the tasks are simpler, and we will provide more guidance. Later, the scenarios get more complex, and we offer fewer hints. (Case 3, senior)

Faculty members of Case 4, the interdisciplinary programme, highlighted the complexities and challenges of supporting students in their research.

> Supporting students to conduct research takes time and patience because, on the one hand, you have this idea of interdisciplinarity; on the other, you have methods of inquiry, and then you have within those methods of inquiry, different assumptions about the world. (Case 4, early-career)

Students in Case 4 were offered more flexibility in terms of the specific 'throughline' a student went through. Faculty members on Case 4 commented on the various research interests and directions students could design for themselves.

> It's like you are pulling together things and developing a kind of intensity around your curriculum for something that you're really passionate about.… One student is interested in beauty, cosmetic science and entrepreneurship, and she wants to develop her own cosmetic company. (Case 4, early-career)

The research-based curriculum experienced by students

The majority of student interviewees (78.8%) viewed their learning experiences as positive. Most students were aware of the various research opportunities and viewed them as useful to their learning. When asked to describe the research-based curriculum, many interviewees mentioned the collection and analysis of information.

> I think research opportunities are sufficient, including collecting information, calculations, analysis, everything is researched and done on our own. …although it takes a lot of effort, I believe they are valuable. (Case 3, Year 2)

Some interviewees (33.6%) highlighted the opportunities to make contributions to the local community through research projects.

> The most important part is that we can make a change in the society…. making a change, you know, [it] inspires me a lot. That's the thing that I think is the most important part of research… (Case 4, Year 2)

Other frequently mentioned experiences referred to exploring something interesting (24.8%) and learning research methodologies and techniques (23.9%). The two most

mentioned factors leading to an effective research-based curriculum were receiving specific guidance from faculty members and having a full-cycle research experience including identifying a problem, conducting literature reviews, collecting and analysing data, discussing findings, and making presentations. Some students valued the opportunities to disseminate their research with peers. For example,

> I really enjoyed making infographics and making the video with our groupmates and showing how recent technologies could help people with Parkinson's disease, so I really enjoyed that programme. (Case 1, Year 4)

Exploring something interesting with personal relevance and learning professional attributes and skills also contributed to a positive learning experience. For example,

> The overall research experience is quite important and meaningful to me, because before I was quite shy; I was not brave enough to present in front of many people…. After enrolling in this programme, I became braver…. In the research internship, I made a presentation to my department head and a lot of people. (Case 3, Year 2)

It is noteworthy that 14.2 percent of all the student interviewees viewed their experiences as negative and seven percent as neutral. For some, research did not match their interests:

> I just want to learn about life but not this theory, not this biological term…. I think this stuff is for people who are interested in doing more research in the biochemical area, but it is just not for me. (Case 1, Year 3)

The most salient negative factor was the stress and confusion caused by the flexibility in the curriculum (29.2%). This was followed by lacking specific guidance (23.0%) and lacking autonomy in designing research topics or methods (7.1%).

Regarding a research 'throughline', approximately one-third of the students had a clear idea of how the curriculum enabled progression from early years to graduation, while a majority only knew roughly some components without a comprehensive understanding of development. Those who had a 'throughline' concept articulated how various courses enabled progression:

> [Programme name omitted] has a series of courses. Like it is a progressive series of courses for you to first learn about what research is and then try to do your literature review and then do your own research. (Case 2, Year 4)

Interestingly, almost all students with a 'throughline' concept had a passion for a specific research topic that they were pursuing or planned to pursue. For example,

> I think the research courses were really helpful for me because they helped me do my research…. I am working on my independent research, which is not aligned with the university or the programme. But it is probably the best experience. (Case 4, Year 2)

Students with a 'throughline' concept were often more critical about the curriculum design compared with those who did not have such a concept. For example,

> My research area is quite specific. The two courses [codes omitted] were not enough for me to do research independently in my senior years. (Case 2, Year 4)

Across the four cases, students' 'throughline' involved a much broader scope than had been written about and taught within the programme. Many non-curricular research

experiences were mentioned as part of students' 'throughline' (e.g. research assistantships in other faculties and research projects organised by the university).

Another experience shared by students across the four cases was that students had to actively seek research opportunities to create a meaningful research 'throughline'. For example,

> I think there are many opportunities to participate in research. But you have to find those opportunities actively. Otherwise, most of your research experiences only focus on doing some lab reports and assignments. (Case 1, Year 4)

For students who did not show an understanding of a 'throughline', lacking purposes or not being able to see the value of research was stated.

> I think, just do this stuff [experiments]…. I just don't enjoy it that much to be honest…. I don't know why it would be useful for me in my future life, but… even though the lab itself is quite boring, working with others is quite enjoyable. (Case 1, Year 3)

Unique features were also identified in each case. In Cases 1 and 3, students often connected their research experiences with the professional they planned to become after graduation. For example,

> I think having these ideas generated in the research projects would be very useful for my future career because we have to give nutritional advice or design meal plans for a lot of people. (Case 1, Year 4)

In Case 2, the 'throughline' concept was especially strong among those who planned to pursue postgraduate study as they leveraged the 'throughline' to discover and confirm their interests:

> I do literature reviews in these different fields and get to figure out what I am really interested in. It helped me in the way that I can finally find direction for my postgraduate studies. (Case 2, Year 4)

Moreover, not being able to attend the overseas laboratory-based internship due to the COVID-19 pandemic, a signature research component in the Case 2 curriculum, was seen as an interruption of the 'throughline'.

In Case 4, students used a 'double-edged sword' to highlight the complexity in the research 'throughline' embedding positivist and interpretivist paradigms:

> It is kind of like a double-edged sword. On the one hand, it does open up a lot more opportunities and subjects that you could possibly choose, but at the same time, it's like you really need to know, like, what exactly you want to research. (Case 4, Year 2)

Discussion

Perceptions and experiences of the research-based curriculum

Examining the declared, the taught, and the learned curricula shows that research-based curricula, according to our working definition, existed to a certain extent in universities

in Hong Kong. However, these curricula and their associated features, for example, connected research activities, opportunities to participate in knowledge production, evaluation, and dissemination, and progressively developing critical thinkers, were interpreted differently by faculty members and students.

A substantial difference was identified between faculty and students regarding the perceptions of opportunities to participate in knowledge production, evaluation, and dissemination. Many students experienced the curriculum as exploring something interesting and collecting and analysing information, which differed from faculty members' focus on acquiring, applying, and evaluating knowledge. What is more concerning is that students seemed less aware of how conducting research could lead to a critical understanding of academic knowledge and its applications and limitations. According to Harland and Wald (2018) and Young (2009), a principal rationale supporting research-based learning is to enable students to acquire powerful knowledge. We believe that a lack of this understanding might be due to insufficient communication with students about the rationale behind research-based curricula. A related finding showed that more than 90 percent of the students did not believe they could make original contributions to the field through research. In other words, many students appeared to experience research more as an assignment than an opportunity to discover new knowledge, which posed challenges to the mission of developing all students as researchers with a researcher's identity (cf. Harland & Wald, 2018).

Another difference between faculty members' perceptions and students' experiences was whether the curriculum offered a taste of the disciplinary research culture. Faculty members seemed to assume that students would acquire how research is conducted in the discipline (or across disciplines in Case 4), while only a few students mentioned this aspect. This discrepancy relates to Walkington et al.'s (2017) finding that students need threshold experiences, for example, multidisciplinary research events, to learn their own disciplinary culture. Walkington et al. (2017) observed that in multidisciplinary settings, students adopt 'Reciprocal Elucidation'—a process in which they exchange views about one another's research as a student-led form of learning from their peers—to gain insights into their own disciplinary norms. This process can help students go out of their disciplinary silos (Hill & Walkington, 2016). Our finding regarding students being less aware of their disciplinary research culture might reflect an insufficient exposure to threshold experiences in the curricula. Though we need to be cautious that not mentioning this aspect in the interviews does not mean its non-existence, we can still suggest that guidance on inducting students into a disciplinary research culture appears to need more work.

Regarding factors contributing to negative experiences of the research-based curriculum, stress and confusion caused by flexibility in the curriculum were the most mentioned. Mahatmya et al. (2017) found that two significant barriers to undergraduates' participation in research were students perceived they were not ready for research and they lacked time. Our study adds a possible explanation that the perceived lack of research readiness might be associated with the stresses and confusion students experienced as they faced an increasing level of autonomy in deciding their research topics.

Interestingly, there were inconsistencies in students' perceptions regarding autonomy. On the one hand, having autonomy was regarded as positive; on the other, many were stressed by an increasing level of autonomy. There are two explanations to these seemingly contradictory findings. One is that there were two groups of students, one welcoming autonomy in conducting research while the other group appeared to be overwhelmed. However, we also identified certain students who enjoyed the autonomy while also experiencing stress and confusion. These students typically required more mentoring support.

Perceptions and experiences of a research 'throughline'

Half of the faculty interviewees showed an understanding of a research 'throughline' embedded in the curriculum, and 36.6 percent of the students believed that they experienced a 'throughline'. Brew and Mantai (2017) distinguish between atomistic undergraduate research design and wholistic design. The former contains little coordination between courses, while the latter implies a 'throughline'. In our findings, only half of the faculty members showed perceptions close to a wholistic approach, which could be related to some of the limitations of research-based curricula. Particularly, the conceptualisations of research-based curricula are inconsistent with the common practice of curriculum planning in most universities. The former requires coordination between all faculty members teaching on the programme, but in many cases, only a few are actively involved in curriculum planning (cf. Wijngaards-de Meij & Merx, 2018)

What was equally concerning was that the curriculum design was not visible to all students. Our findings suggest that it was individual students' agency that enabled them to appreciate the 'throughline'. Student agency, the ability to act reflexively in a learning environment (Archer, 2000), has been connected with positive learning outcomes, but its role in research-based curricula has not been sufficiently examined. Our study further exemplifies the role of agency as students who had a concept of a research 'throughline' exhibited a critical review of the curriculum design. Agency enables students to actively seek research opportunities and become more reflective about their learning. These insights add weight to Clark and Hordosy's (2019) findings, stating that student experiences of the curriculum depend on individuals' interests.

Cross-case comparison

The cross-case comparison shows several patterns. First, the Case 4 curriculum distinguishes itself by its interdisciplinary research focus and a more complex 'throughline'. Different from the 'throughline' that runs in conjunction with the hierarchical curriculum in the ecology programme (cf. Harland & Wald, 2018), the interdisciplinary programme in our findings shows a 'throughline' that exposed students to two research paradigms in the first year and allowed them to pursue their own directions in later years. In other words, this 'throughline' was co-constructed by the programme and students.

Similarities and differences were also identified among the cases in science disciplines. The first three cases showed features of a hierarchical knowledge structure, echoing Becher's (1989) proposition that knowledge in hard disciplines is cumulative, hierarchical, and quantifiable. In our findings, such a feature was reflected in a research 'throughline' that started from foundational knowledge, to the learning of research and laboratory techniques, to hypothesis development, and finally capstones integrating knowledge and skills. These findings pose a challenge to the literature stating that it is difficult to integrate research into teaching in hard disciplines due to their hierarchical knowledge structure (cf. Colbeck, 1998). We found that a hierarchical structure provides a framework for designing the 'throughline'.

Cases 1 and 3 (applied science) are concerned with connecting the research activities with communities. The Case 2 (pure science) curriculum, in contrast, displayed a stronger orientation towards supporting students for postgraduate research while showing less evidence in connecting with communities. These findings illustrate the relevance of Becher's

(1989) typology (i.e. classifying disciplines into hard-pure, hard-applied, soft-pure, and soft-applied) in analysing research-based curricula as the features of the first three cases align with their corresponding categories in the typology. That said, the emerging interdisciplinary programmes call for more nuanced classifications to effectively examine programmes such ecology or the one in Case 4 in our study.

Implications

Despite the positive views of the research-based curriculum among faculty members and most students, there is much room for improvement in the curriculum conceptualisation, design, and implementation. The first implication concerns awareness of the rationale supporting the curriculum design and the visibility of a research 'throughline'. More communication with students about the purpose of conducting research is desirable (cf. Hughes, 2019).

An understanding of a 'throughline' is beneficial, but our findings imply that it takes effort to engage faculty members and students in developing an understanding of the curriculum as a whole. With more institutions implementing research-based curricula, examples of good practices might be collated to inform faculty members of the curriculum design principles. This preparatory task, together with curriculum reviews in different years of the programme, might help develop an overall understanding.

Furthermore, mentoring students in the research-based curriculum is important, and faculty members as mentors need training (cf. Walkington et al., 2020). According to Shanahan et al. (2015), effective mentoring should involve inducting students into the norms of the discipline, enabling them to reflect on what distinguishes research in their discipline, and navigating the unwritten rules of research. These practices help create a conducive environment for 'Reciprocal Elucidation' (Walkington et al., 2017).

Another implication concerns a broad conception of the 'throughline' among some students who value non-curricular research activities. Curriculum leaders can empower students to track their growing understanding of research and competency in research skills as they proceed through curricular and co-curricular experiences. These records could be put together in a research portfolio for students to gain credits.

Limitations

This study has several limitations. First, it possibly suffered from selection biases since those agreeing to participate tend to view research-based learning positively. We tried to mitigate the negative impact of this limitation by encouraging participants to express their views as freely as possible. Our relatively large sample of student interviewees (i.e. 113 in total) also suggests that a diverse range of opinions were hopefully captured.

The second limitation is related to working with student co-researchers. Although involving student co-researchers as interviewers provided benefits, we nevertheless identified room for improvement. For example, one co-researcher asked in the interview: 'Our programme has plenty of great research elements. What is your view?' This question would be seen as too direct with leading information by experienced interviewers. We supported co-researchers by reviewing the recording of their first two interviews and providing feedback.

Thirdly, involving only two institutions might limit our implications. We tried to triangulate data from documents, faculty interviews, and student interviews to overcome this limitation.

Fourthly, we as a group of enthusiastic researchers might unconsciously attempt to confirm the positive aspects of research-based curricula. As remarked by Merriam (1998), all observations and analyses in interpretive studies are filtered through researchers' values. We therefore strived to examine both confirming and disconfirming evidence.

Conclusions

A research-based curriculum with potential for developing 'powerful knowledge' and critical thinkers becomes crucial in the post-truth era. We offered an in-depth understanding of how the research-based curricula were reflected in the documents, perceived by faculty members, and experienced by students. Our main contributions are the identification of gaps between faculty members' perceptions and students' experiences, pointing out the insufficient awareness and communication of the rationale for adopting a research-based curriculum. Moreover, our findings on the research 'throughline' reveal an inadequate understanding of the progression across the entire curriculum among both faculty members and students, which places limitations on the extent to which the expected outcomes to develop students as researchers were able to be realised. More transparent communications about the curriculum between faculty members and students are essential in building a consensus on designing and supporting undergraduate research. These practices might offer an opportunity to better connect faculty's teaching with the purpose of higher education to develop critical thinkers. Finally, future research might consider refining the conceptualisations of research-based curricula by incorporating interdisciplinary perspectives as well as the connection with research activities beyond the curriculum.

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Declarations

Conflict of interest The authors declare that there exists no competing financial interest or personal relationships that could have appeared to influence the work reported in this paper. The second, third, and fourth authors are faculty members in the two universities where the study was conducted. All authors personally support the adoption of research-based curricula. However, there are no associations between the work reported and potential/actual benefits to any author. In addition, how we handled our positionality has been described as part of the research design on p.5.

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