Introduction

The calculus renewal effort continues to have a significant impact on undergraduate mathematics education. Today, most new editions of calculus texts, even so-called traditional ones, incorporate significant themes and problems developed as part of the calculus reform movement. On the other hand, the mathematics community has paid little attention to the courses that precede calculus, most notably precalculus and college algebra. Moreover, only a small percentage of students who take precalculus ever go on to take calculus, and many who do are not well prepared and never complete the next course. In response to these concerns, the conference, *Rethinking the Preparation For Calculus*, was held in October, 2001. Since the papers presented at the conference form the basis for this volume, the volume begins with an overview of the conference co-authored by Jack Narayan, the principle organizer of the conference, and with the text of the keynote address given by Lynn Steen. The twenty questions about precalculus that Lynn posed guided many of the discussions at the conference. As you read about the conference in the initial papers in this section and in the papers that follow, please keep in mind that the focus of the conference was on precalculus courses that are not terminal—that is, on courses that prepare students to take calculus. During the conference it became apparent that this focus was too narrow and consequently the focus of this volume was extended to include the courses below calculus. Also please keep in mind that four years have passed between the conference and publication of the volume.

> The purpose of the conference was to rethink the preparation for calculus, with the following considerations: (1) Students are having different mathematical experiences in high school. The routine use of graphing calculators is standard, there is a greater emphasis on group work and collaborative learning, and there is a growing emphasis on conceptual understanding and realistic problem solving, not just skill development. (2) Calculus in college is placing different expectations on students, particularly an emphasis on conceptual understanding and the use of technology. (3) New technologies provide a wider selection of tools for both the teaching and learning of mathematics. (4) College algebra courses are in the process of changing. [The intended outcomes of the conference included:] articulating principles for changing precalculus offerings and providing guidance to the mathematical community.
>
> *The Conference: Rethinking the Preparation for Calculus*
> Jack Narayan and Darren Narayan

> Approximately fifteen years ago, a workshop similar to this one took place at Tulane University where a merry band of reformers sought to make calculus lean and lively. I had the opportunity to address that workshop with a list of twenty questions for calculus reformers. Thus I thought it appropriate to take a similar approach to this current workshop, to help launch your work by asking twenty questions about precalculus.. . . Clearly precalculus (and its alter ego college algebra) is the single most common mathematics course in undergraduate education. Data aside, it also appears to be the rock on which college students' mathematics education most often founders. That dark secret is why we are all here.. . . To reflect on the issues, to “rethink precalculus,” as this workshop intends, nothing can beat the journalist's simple questions, [what, who, why, when, where, and how?]
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> *Twenty Questions about Precalculus*
> Lynn Arthur Steen

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The Conference: Rethinking the Preparation for Calculus

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Editor's note: The papers presented at this conference form the basis for this volume. This article, which was written shortly after the conference was held in October 2001, gives the rationale for the conference. For a more up-to-date view on some of the issues discussed here, please see the article, "Where Do We Go from Here: Creating a National Initiative to Refocus the Courses below Calculus," by Sheldon Gordon, later in this volume.

Rationale for the conference

During the last decade, calculus renewal efforts occured at all levels of post-secondary institutions as outgrowths of the Tulane Conference in 1987 and the subsequent national conference on *Calculus for A New Century*, hosted by the National Academy of Sciences. An MAA special report, *Assessing Calculus Reform Efforts* [1], estimated that "at least 150,000 students or 32% of all calculus enrollments in the spring of 1994 were in reform courses." Since 1994, several reform calculus texts have been among the highest selling nationally, and the number of institutions utilizing one or more aspects of reform in their calculus courses continues to rise. The calculus renewal movement continues to have a significant impact on undergraduate mathematics education. Instructors have experimented with alternative teaching methods that included the use of technology, collaborative learning, and out-of-class projects. These methods were integrated into new curricula with an increased emphasis on conceptual understanding. Today, all new editions of calculus texts, even so-called traditional ones, incorporate significant themes and problems developed as part of the calculus renewal movement.

One major, although unanticipated, outcome of the calculus renewal effort is the development of comparable efforts to revise college algebra and developmental mathematics offerings. There have also been several efforts to rethink precalculus courses, most notably those by Baxter Hastings, Connelly et al, and Gordon, et al. However since the publication of the volume, *Preparing for a New Calculus* [2], the mathematics community has paid insufficient attention to courses that bridge precalculus courses with calculus courses. The need to address this issue is essential since, as Lynn Steen points out, "Clearly precalculus (and its alter ego college algebra) is the single most common mathematics course in undergraduate education." The enrollment data in the fall of 2000 supports Steen's statement. In particular, the precalculus enrollment then was twice the enrollment of calculus I at all types of institutions and four times the enrollment of calculus I at two-year schools [12]. It is now time to renew a national dialogue on these issues.

The *Rethinking the Preparation for Calculus* project focused on precalculus courses that are not terminal—that is, those that are requirements for some type of calculus. All of us are aware, in general, that only a small percentage of students who take precalculus courses ever go on to take calculus and that many of them who do are not particularly well-prepared for calculus and never complete the course. But this has never been carefully documented. In a comprehensive study done at the University of Lincoln at Nebraska, Steve Dunbar found just how small that percentage actually is [13]. As a result, large numbers of students lose the opportunity to pursue mathematics or mathematics based disciplines. Mathematics instructors can readily identify with the observation noted in [3]:

> Students who were substantially underprepared reported more conceptual problems and feelings of being overwhelmed in the early stages of their major… Not only did most of these students abandon their ambition to continue with a S.M.E. (Science, Mathematics, and Engineering) major, they also suffered emotional damage by attempting what proved an impossible task.

Several colleges and universities, for example, University of Michigan, University of Texas at El Paso, and SUNY Farmingdale have recognized the need for rethinking the precalculus curriculum and have implemented completely different approaches.

Furthermore, given the importance that two and four-year schools attach to the development of articulation agreements among two and four-year schools, it is essential that there should be some serious discussion on the topic in conjunction with any discussion of changing precalculus courses.

Overview of the conference

At the 2001 joint meetings in New Orleans, Jack Narayan discussed the idea of having an NSF-funded conference focusing on the precalculus curriculum and was encouraged to develop a proposal. Shortly thereafter a steering committee was formed consisting of Jack Narayan (chair), Steve Dunbar, Sheldon Gordon, Nancy Baxter Hastings, Christopher Hirsch, and Jo Ann Lutz.

The committee proposed to organize a special invited conference to bring together mathematicians with a deep interest in this topic. The purpose of the conference was to rethink the preparation for calculus, with the following considerations:

1. Students are having different mathematical experiences in high school. The routine use of graphing calculators is standard, there is a greater emphasis on group work and collaborative learning, and there is a growing emphasis on conceptual understanding and realistic problem solving, not just skill development.
2. Calculus in college is placing different expectations on students, particularly an emphasis on conceptual understanding and the use of technology.
3. New technologies provide a wider selection of tools for both the teaching and learning of mathematics.
4. College algebra courses are in the process of changing.

The expected outcomes of the conference included:

- articulating some principles for changing precalculus offerings
- providing guidance to the mathematics community
- developing a cohesive effort among those individuals who have done groundbreaking work in this area to make a larger impact on the mathematics community
- focusing attention on problems and needs in the precalculus area that will lead to new funding programs/opportunities from NSF and other funding agencies
- publication of the conference proceedings as a volume in the MAA Notes series

The proposal for the conference was funded by the National Science Foundation (DUE 0136162) and the Calculus Consortium for Higher Education (CCHE). In the fall of 2001, fifty-five mathematics educators participated in the invited conference in Arlington, VA to rethink the preparation for calculus. The major themes for the conference included:

- Transition from high school
- Changes in college algebra
- Precalculus reform projects
- Technology
- Implementation issues
- Research in student learning
- Influencing the mathematics community

Invited position papers for each theme were presented and discussed. Participants were then encouraged to help identify challenges and make recommendations. This MAA Notes volume represents the contributions of many of the participants.

The discussions were based on a series of basic principles about precalculus courses that are stated and addressed by Nancy Baxter Hastings and Sheldon Gordon (see [14], [15]):

- Precalculus courses serve two distinct student populations: the overwhelming majority for whom precalculus is a terminal course and the relatively small minority for whom it is a gateway to higher mathematics. The needs of both populations should be met.
- Precalculus courses need to prepare students for calculus both *conceptually* and *algebraically*. It is not enough just to emphasize the development of manipulative skills; students need help to learn how to understand and apply the basic calculus concepts. Very few students have the ability to develop those conceptual connections on their own.
- Calculus is no longer the first mathematics course that is considered a prerequisite for courses in other quantitative disciplines. Precalculus and college algebra are now prerequisites for (non-calculus-based) courses in many fields. The mathematical needs of those fields are often not satisfied by standard, algebra skills-oriented precalculus/college algebra courses.
- Students need to see an emphasis on mathematical modeling to learn how mathematics is connected to the real world. The basic mathematical concepts and methods should be developed in contexts to help the students transfer their learning outside the mathematics classroom.
- Precalculus courses should help students learn to use modern technology wisely and appropriately.

Moreover, current research into the learning process has much to tell us about how students acquire fundamental precalculus (mathematical) concepts. Only a small minority of students learn mathematics the way their professors did.

The original intent for the conference was to focus exclusively on precalculus courses that are intended as the immediate precursors to calculus. However, the discussions at the conference almost immediately demonstrated that it was impossible to separate such precalculus courses from all precursor courses, especially college algebra. As a consequence, most of the comments in this article, as well as the current volume in its entirety, reflect this broader vision.

The principal recommendation from the conference was to collect extensive data from many different types of institutions to identify which students take precalculus (and college algebra) courses and why they take these courses. In addition, it was recommended that data be collected concerning the success rates in these courses, which successor courses the students actually take, and how they do in successor courses. The conference participants felt that such data is critical for convincing the mathematics community at large that precalculus courses need to change, as well as to acquaint potential funding agencies of the magnitude and implications of the problem. Moreover, the participants felt that any efforts to rethink precalculus should involve high school mathematics teachers and faculty in client disciplines.

Some conclusions

The task facing the mathematics community is challenging. Although changes in the curriculum are essential, the need to develop a process to improve learning and teaching, particularly at these introductory levels, is greater. In many ways, the "teaching gap" is as readily evident in the higher education mathematics curriculum as it is in the school system [4]. The authors observe that:

> American teachers aren't incompetent, but the methods they use are severely limited, and American teaching has no system in place for getting better. It is teaching, not teachers that must be changed... Teachers present definitions of terms and demonstrate procedures for solving specific problems. Students are then asked to memorize the definitions and practice the procedures. In the United States, the motto is "learning terms and practice procedures."

Mathematics instruction in traditionally-taught courses appear to be locked in a cycle. Many incoming college students are underprepared for calculus. College professors, despite good intentions of stressing conceptual understanding and mathematical modeling, have often yielded to the teaching of procedures because of time and syllabi constraints. As a result of this culture, the next generation of teachers adopts similar teaching strategies. In turn, their students arrive at college expecting to be taught in the same way they learned in high school. This cycle must be broken simultaneously at all levels. NCTM's efforts to encourage adoption of its Standards have made major gains at breaking the cycle at the school level, but it must be addressed at the college level as well.

The conference on *Rethinking the Preparation for Calculus* attempted to lay the foundation for change by reaching out to all constituents. This includes groups that have been instrumental in bringing about comprehensive change in the secondary curriculum, change in the calculus curriculum, adoption of technology at all levels of mathematics instruction, and a more informed view of mathematics education among college and university administrators. This collaborative effort will have a good chance of developing a process upon which we can improve in time. The papers in this MAA Notes volume describe the problem, begin the process of data collection, give examples of successful practices using mathematical modeling, new technologies, alternative learning strategies, assessment of student learning, and outline possible next steps.

On the positive side, mathematics educators, mathematical organizations, and politicians are beginning to recognize the need to go beyond curriculum renewal and focus instead on developing plans to improve learning and teaching. Recent publications provide the theoretical basis to develop a more efficient and effective process for the improvement of learning (see [5], [6], [7], [8], [9], [10]).

The individuals who sparked the movement to revitalize the teaching of calculus stressed that calculus should be "a pump, not a filter." Taking precalculus should be a positive experience for all students, not just the handful who pursue mathematically intensive fields. This requires rethinking precalculus. After all, a pump is only as good as the motor that powers it.

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2

Twenty Questions about Precalculus

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Editor's note: This paper is the text of the keynote address given by Lynn Steen in October 2001 at the conference Rethinking the Preparation for Calculus. (For an overview of the conference, please see the preceding paper in this volume by Jack Narayan and Darren Narayan.)

Introduction

Approximately fifteen years ago a workshop similar to this one took place at Tulane University where a merry band of reformers sought to make calculus lean and lively. I had the opportunity to address that workshop with a list of twenty questions for calculus reformers. Thus I thought it appropriate to take a similar approach to this current workshop, to help launch your work by asking twenty questions about precalculus. (For comparison, I reproduce in Appendix A the questions that I put before the calculus reformers at Tulane. There you will find not 20 but 28 questions, the extra eight being added to the manuscript as a result of issues raised during the workshop. The full text with elaborations on each question can be found in [3].)

At the time of the Tulane workshop I was President of the Mathematical Association of America, and in that capacity had some degree of oversight responsibility for MAA's many committees. Even as the Tulane rebels were training their sights on calculus, I was well aware that then, as now, more college students study precalculus than calculus. On several occasions I asked the CUPM subcommittee on the First Two Years (later to be renamed CRAFTY—Calculus Reform and the First Two Years) whether in order to fulfill the mission implied by their title they might be interested in looking at the mathematics course that is the most common of all taken during students' first two years in college, namely precalculus. Their answer was consistently negative: precalculus, in their judgement, was an unfortunate leftover from high school mathematics. Despite enrollment evidence, they said, college mathematics begins with calculus.

With this fifteen-year-old experience as backdrop, I checked current data to see what enrollments look like now. Figure 1 offers a sobering portrait of undergraduate mathematics prepared by combining recent data from two sources—the (forthcoming) quinquennial CBMS 2000 survey [2] and the annual AMS survey [1]. (Enrollments included in this figure are predominantly in departments of mathematical and statistical science. They do not count the many statistics, computer science, and applied mathematics courses found outside departments of mathematics or statistics.) Clearly precalculus (and its alter ego college algebra) is the single most common mathematics course in undergraduate education. Data aside, it also appears to be the rock on which college students' mathematics education most often founders. That dark secret is why we are all here.

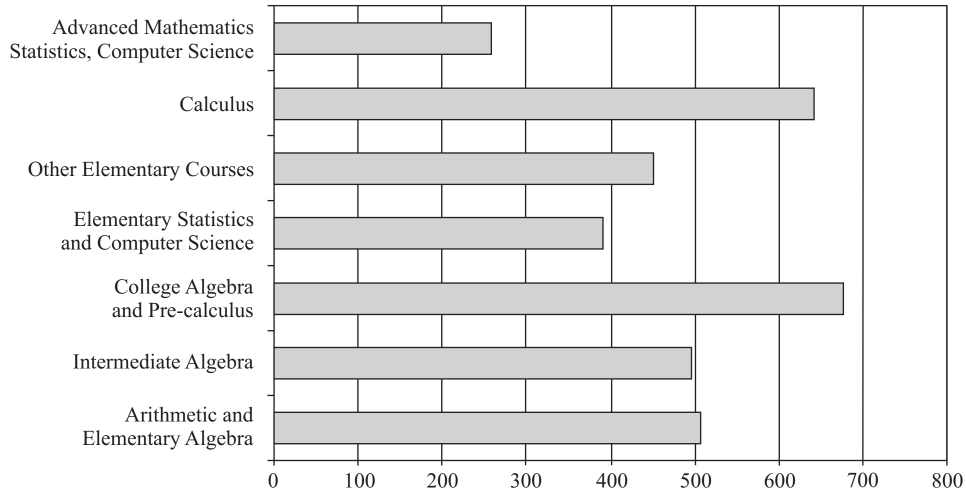

Figure 1.

One can approach the challenges of precalculus from several perspectives. For example, a managerial perspective would suggest a cycle of setting goals, developing strategies, implementing changes, assessing outcomes, reflecting on results, and making adaptations. A journalist's paradigm, in contrast, seeks insight by asking questions: what, who, why, when, where, and how? To actually make changes that improve student learning, the managerial paradigm is really the only effective option: set a goal, make some changes, look at the results, and then regroup. But to reflect on the issues, to "rethink precalculus" as this workshop intends, nothing can beat the journalist's simple questions.

What?

What exactly is precalculus? Is it the same as college algebra? (In this analysis, I ignore whatever differences there may be between them.) Does precalculus have an intellectual core like geometry or calculus? Does it have a center or a town square? Or is it more like a mathematical strip mall that just fills space between high school and college?

What is the real goal of precalculus? Is it really to prepare students for calculus, or does it have other purposes, either benign or sinister? Isn't it also, *de facto*, a ubiquitous prerequisite for a wide range of quantitatively-oriented college courses, a steady source of tuition revenue that reliably exceeds marginal costs, and an accepted means of screening students for access to the economic rewards of higher education?

What effect does calculus have on the nature of the precalculus course? What differences are there in preparation for reformed calculus, for traditional calculus, for mainstream calculus, or for non-mainstream (business) calculus? Can a single course provide suitable preparation for all flavors of calculus? Can precalculus possibly be made lean and lively?

Who?

Who takes precalculus? Is its clientele students who are reviewing (or relearning) what they once learned, students who did not learn what they once studied, students who never had the opportunity to learn precalculus topics, or students who declined the opportunity? In most courses, the answer is "all of the above." Can a single course really serve all these different students?

Who should take precalculus? Does precalculus serve well the quantitative needs of students preparing for fields that do not require calculus? Does it offer any lasting benefit for students who never take any further mathematical or quantitative course? For that matter, does precalculus really benefit the students it was created to serve—those who need calculus but are not ready for it?

Who should teach precalculus? University mathematicians? Teaching assistants or adjuncts? Experienced secondary school teachers (who perhaps teach the very same course during the day to high school students)? What about on-line tutorials? Is a Ph.D. in mathematics an appropriate credential for teaching precalculus? Might mathematicians' uncommon facility with elementary mathematics make them peculiarly inappropriate as empathetic teachers of precalculus?

Who benefits from precalculus? Who loses? Does precalculus have disparate impact on at-risk populations? For whom, if anyone, does precalculus serve as a pump? For whom is it a filter? Some believe its primary beneficiary is the budgets of mathematics departments for whom it serves as a cash cow. Maybe it is just a means of shifting tuition income from a required large enrollment course to low enrollment advanced electives—that is, from the mathematically weak to the mathematically strong.

Why?

Why is calculus so important for under-prepared undergraduates? Is preparing for calculus really a wise use of college students' time and energy? Might the siren call of calculus replace more important goals for students who enter college unprepared for calculus? Shouldn't more under-prepared undergraduates be steered in other quantitative directions?

Why do students take precalculus? Is it to prepare for calculus, to meet the prerequisite of a particular course or program of study, to fulfill a general education option, or to fulfill a graduation requirement? Are any of these reasons defensible, or are they simply traditional?

Why is precalculus so often part of general education? Does precalculus advance students' mathematical or quantitative literacy? Does anyone believe that precalculus is the right mathematics course to prepare students well for lives in the 21st century? Does it reveal important insights into the nature, power, and beauty of mathematics? Can precalculus possibly serve two masters—calculus and culture?

Why should students take precalculus? Does precalculus have value for the majority of students who take the course? Are its concepts and skills independently useful apart from their role in calculus? How many ever use the skills they learn in precalculus? Is precalculus a sensible choice for the last mathematics course a student ever takes?

Why do so many prospective elementary school teachers take precalculus? In the majority of departments, precalculus (or college algebra) is the second most common course taken by students preparing for K–3 certification [2]. Does this make any sense? Does precalculus really provide teachers with deep understanding of the mathematics they will be teaching?

When?

When should students take precalculus? Is there an optimal window for learning precalculus? Isn't precalculus taught and learned better in high school? Currently only about 25% of high school graduates take precalculus in high school, even though over 60% enroll in some form of postsecondary education. Shouldn't higher education tell students and schools that it is more important for more students to finish precalculus in high school than for more students to finish calculus?

Where?

Where do precalculus students come from? What have been their mathematical backgrounds? What are their major programs of study or career interests? How many are returning after having interrupted their study of mathematics? How do students' prior mathematical experiences influence their views of mathematics, their confidence in their own abilities, and their likelihood of success with precalculus?

Where do precalculus students go? How many precalculus students eventually take calculus? (*Answer*: Relatively few.) How many take other courses that utilize ideas from precalculus? (*Answer*: A few more.) How many complete a year of calculus with good grades and incentive to continue their study of mathematics? (*Answer*: Embarrassingly few.) For how many is precalculus the end of their study of and interest in mathematics? (*Answer*: Far too many.)

How?

How should the changing role of mathematics influence the nature of precalculus? In the last two decades mathematical practice has become increasingly algorithmic and digital. New applications range from genomics to cinema, from manufacturing to Wall Street. How, if at all, should the content of precalculus reflect this expanded interface of mathematics with the rest of the world?

How do articulation agreements constrain precalculus? Are inter-institutional agreements on syllabi and standards essential instruments of quality control? Or do tight curriculum specifications lead to curricular sclerosis? Are the transparency benefits of articulation agreements worth the cost of inflexibility and stifled innovation? On balance, do students gain or lose from these protocols?

How well aligned is precalculus with common placement tests? Do commercial or homegrown placement tests reflect the same level and type of performance expectations as a precalculus course? Do they accurately place students into or out of precalculus? Are they fair to students?

How should technology influence precalculus? Is technology a means or an end? Is its role to help students learn traditional mathematics, or is technology now so much part of the way mathematics is practiced that it has itself become an important goal of instruction? Is the use of numerical, graphing, and CAS systems a prerequisite to learning calculus?

How do you measure success? This may be the toughest question of all. Fewer than one in four students, perhaps as few as one in ten, achieve the *prima facie* goal of precalculus: to succeed in calculus. Without clarity about goals, it is impossible to gauge success. Without data on students' future academic careers, success is unknowable. And without external validation, precalculus may never improve.

Conclusion

These questions suggest an overwhelming agenda for a course of enormous importance, but a course that is all but invisible to the mathematical community. I wonder how much has really changed in the last fifteen years since CRAFTY's predecessor declined to take up the challenge? Neither enrollment patterns, course prerequisites, nor general education requirements have changed very much. Nor, I suspect, have mathematicians' attitudes about what constitutes appropriate college mathematics. Does the mathematical profession now consider precalculus a challenge worth working on, or do they still see it as a peripheral problem best ignored? Can any mathematician earn tenure by teaching or improving precalculus? (That's a rhetorical question.)

In addition to seeking answers to the twenty questions I have suggested, the merry band of reformers assembled for this conference will need to think hard about where precalculus fits into the agenda of mathematics, of science, and of our nation. Rethinking precalculus may lead to some surprising conclusions.

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Appendix A

Twenty Questions for Calculus Reformers
Lynn Arthur Steen, January, 1986 (From [3])

1. Should fewer students study calculus?
2. Is calculus an appropriate filter for the professions?
3. Will computer science dethrone calculus?
4. Do students really learn the major ideas of calculus?
5. Has calculus become a cookbook course?
6. Does calculus focus excessively on closed-form formulas?
7. Should calculus students learn to use or to imitate computers?
8. What new topics are essential for calculus in a computer age?
9. Which topics in calculus are no longer essential?
10. Do engineers still need the traditional calculus?
11. Should calculus be a laboratory course?
12. Is there any reason to teach high school calculus?
13. Why do U.S. students perform so poorly on international tests?
14. Is there any value to precalculus remedial programs?
15. Why do calculus books weigh so much?
16. Can one design a good calculus course from a survey?
17. Is calculus a good course to train the mind?
18. Can calculus courses convey cultural literacy?
19. Does calculus contribute to scientific literacy?
20. What will calculus be like in the year 2000?

Added after workshop discussion:

21. Do students ever read their calculus books?
22. Should precalculus be a prerequisite for calculus?
23. Is teaching calculus most like teaching a foreign language?
24. Should the student-faculty ratio for calculus be limited?
25. Do student evaluations favor calculation-based courses?
26. Are there enough qualified calculus teachers?
27. Who will be the calculus teachers in the year 2000?
28. Should calculus be taught only by experienced teachers?