Taking introductory physics in studio, lecture, or online format: What difference does it make in subsequent courses, and for whom?

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At large institutions of higher education, students frequently have a choice whether to attend the introductory physics sequence asynchronously online, on-site in a traditional lecture setting, or in a reformed studio setting. In this study, we investigate how these different settings are correlated with measures of self-efficacy, interest in physics, and success in subsequent physics and engineering courses, which have the introductory physics sequence as prerequisites. As previous research indicates, some of these measures may depend on gender. We found that the course setting had no significant correlation with the grade in subsequent courses, but that studio settings gave students the feeling of being better prepared, particularly for subsequent courses that included laboratory or recitation components. We also found that gender was correlated with measures of interest in physics, where female students expressed significantly less interest in the subject, regardless of course setting.

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I. INTRODUCTION

The influence of the course delivery modes on learning outcomes has been studied extensively across disciplines in general [1–3], as well as for physics courses in particular [4,5]; the topic received renewed attention due to the COVID-19 pandemic [6]. While the general consensus appears to be that there is no significant difference regarding learning outcomes as measured by exams, there are hints of nuances: for example, students in online courses were found to be more likely to drop out, but those who persist are more likely to achieve higher grades [7]. Also, certain course formats are more successful than others when it comes to conceptual understanding as measured by concept inventories, most notably active-learning approaches [8,9], and in particular face-to-face studio format versus face-to-face traditional format [10,11]. Unfortunately, passing courses with good grades as measured by exams can become the sole focus of students, particularly if interest in the subject is missing [12].

Beyond the overt curriculum, which is traditionally all that is assessed on exams, course instructors frequently have additional objectives related to attitudes [13], expectations [14–16], curiosity [17], beliefs [18], communication [19], “thinking like a physicist” [20], and thinking of themselves as a physicist [21]; the latter touches on issues of identity [22] and self-efficacy [23]. These nonovert curricular objectives can also help students prepare for their careers after college [24].

Many research-based teaching practices aim to foster both the overt and the “hidden” curriculum. For example, team- and project-based learning, as it is frequently practiced in studio-based courses, can decrease the persistent gender gap in self-efficacy [25]; also, course culture can play an important role in conveying the hidden curriculum [26]. Unfortunately, despite using research-based instructional methods, still many of these desirable characteristics generally tend to decrease over the course of instruction [14,21,27,28], which is particularly detrimental, since these epistemological factors may eventually influence learning success in the overt curriculum [29–31]; reverse direction of this relationship is possible, though, when it comes to gender differences [32]. It is thus an important topic of research to determine how different

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course formats and different modes of instruction during what is often students' first exposure to physics can foster self-efficacy and expertlike beliefs and expectations, and how different learning environments in the introductory courses can contribute to long-term success in STEM-related fields [27]. Can different course formats have an impact on both subject matter and "hidden" learning objectives beyond the end of the course and into future studies?

Wilcox *et al.* conducted a longitudinal study on the retention of mechanics concepts (overt curriculum) from an active-learning course after the end of the second-semester course [33]; they found a high level of retention with students maintaining the same scores on a concept inventory one semester later. This is not a given, as conceptual mastery of physics concept can significantly decay within weeks, though differently for different instructional methods [34]. Cwik and Singh studied beliefs about physics and about students' physics learning longitudinally in a two-semester introductory physics course sequence where women are not underrepresented [35], in particular self-efficacy, identity, and interest in physics (hidden curriculum). They found that male learners report higher self-perceived competence, see themselves more as a "physics person" and express more interest in physics than female learners. Rodriguez *et al.* conducted a longitudinal investigation of student performance and persistence in upper-level physics courses after having previously experienced research-based teaching methods in their introductory physics courses [36]. They found that the highest failure risk occurs in the first semester of upper-division course taking, and they emphasize the need for additional longitudinal studies.

In our case study, we surveyed the students at the end of engineering or advanced physics courses for which the introductory calculus-based sequence are prerequisites (thus extending one semester further than the former longitudinal study by Wilcox *et al.*, as well as by Cwik and Singh, and after the semester found to be most risky by Rodriguez *et al.* [36]). In our study, for their introductory courses, our students were free to choose online asynchronous, face-to-face lecture, or studio-based environments, which allows for comparison between these instructional methods. Our main research question is whether the mode of instruction of the introductory sequence influences success in future courses, as well as retained self-efficacy and interest in physics, with a particular focus on gender.

The labels Online, Lecture, and Studio in our study need to be understood as implementations of the general design principles, which, however, are necessarily specific to the institution and the instructor. The same design principle, such as studio physics, can be implemented in very different ways [37] and that implementation can also deteriorate over time [38]. At the same time, the three course types compared here are taught in very different ways: different synchronicity, different levels of active learning, different class sizes, and different interaction patterns among students and between students and instructors. Thus, within the institution, where our study was conducted, the design principles have led to implementations that are distinct enough to expect some long-term impact on student success and self-efficacy.

II. SETTING

Michigan State University is a public, large-enrollment (>50, 000 students) R-1 university. Almost 78% of the undergraduate population is from Michigan. About 47% of the students identify as male and 53% as female.

We considered three types of calculus-based introductory physics courses, namely asynchronous online, lecture-based, and studio-based offerings. Students were free to choose which type, of course, they enrolled into (even though, their choice may have been limited by external factors such as schedule, continuing concerns about the pandemic, anxiety about crowded spaces, or the necessity to commute [3,39]).

The online courses were taught asynchronously using a variety of multimedia components [40]. The lecture-based courses were partially flipped but included traditional in-person lectures [5]. Finally, the studio-based courses were taught using the Projects and Practices in Physics (P-Cubed) pedagogy, which is a highly interactive, community-of-practice (COP) approach [41,42].

As subsequent courses, we considered the engineering and more advanced physics courses which have the calculus-based introductory sequence as a prerequisite. Some of these had associated laboratories or recitations while others had not. In these courses, female students are traditionally underrepresented, with only 25% of the undergraduate engineering and under 20% of the undergraduate physics majors identifying as female.

III. METHODOLOGY

A. Survey administration

An online survey was anonymously distributed at the end of 2 advanced physics and 11 engineering courses for which the calculus-based physics courses were a direct prerequisite listed in the catalog of courses. We were not considering second-order prerequisites; for example, if calculus-based physics is a listed prerequisite for course A, and course A in turn is a prerequisite for course B, we did not consider course B. While students could have been enrolled in more than one of the subsequent courses that we considered, the survey tool only allowed them to submit one answer (using cookies), and they would have needed to choose which course to pick for their responses.

As the authors had no access to enrollment lists, the chair of physics and an assistant dean of engineering emailed the survey invitations to the students in those subsequent courses; this amounted to approximately 100 invitations to students in advanced physics courses, as well as approximately 1100 invitations to students in biosystems, civil, electrical and computer, mechanical, and materials science and engineering courses. The enrollments in these subsequent courses correspond to the approximately 1400 students being enrolled in second semester, calculus-based introductory physics courses each year.

B. Survey variables

Table I shows the surveyed variables; except for gender, as well as the course types and their attendance frequencies, these variables have been coded as Likert scales [43]. We adopted the physics self-efficacy and interest variables from the study by Cwik and Singh [35], and in addition, students were asked which introductory physics courses they had previously taken and what their grades in the altogether three courses were. For readers interested in replicating the study, a typeset copy of the online survey is available in the Supplemental Material to this article [44].

C. Considered subsamples

For the subsequent third course (denoted *AnyCourse3*), we distinguished between those that had laboratory or recitation components (denoted *LabRecCourse3*) and those that did not (denoted *NoLabRecCourse3*). We also separately considered the advanced physics courses (denoted *PhysicsCourse3*); the students in these courses would most likely be physics majors since those are not required for other majors. These distinctions allowed us to separately evaluate the relationships between the variables in Table I within the subsamples of students having enrolled in these different classes of subsequent courses.

D. Statistical methods and limitations

Calculations for simple descriptive statistics were carried out using Microsoft Excel, while correlation analyses and multiple linear regressions were calculated using *R* [45]. In particular, the libraries qgraph [46] and HMisc [47] were used. For correlation matrices, only survey responses that had entries for all considered variables could be evaluated. For analyses considering the variable *HelpLabRec*, only the subsample *LabRecCourse3* was evaluated.

IV. RESULTS

A. Response rate

A total of 107 survey responses were received, of which 104 were completely filled out; this corresponds to an overall response rate of approximately 10%. The response rate was much higher for advanced physics courses (30 responses from 100 invitations) than for the engineering courses (74 responses from 1100 invitations).

TABLE I. Survey variables used in this study. In the values column, the Likert scales [43] were transcribed into integer numbers, e.g., the responses "NO!," "no," "yes," and "YES!" used by Cwik and Singh [35] were evaluated as 0, 1, 2, and 3, respectively.

Label	Values	Survey prompt or definition
Concepts	NO! = 0 – YES! = 3	"I understand concepts I have studied in physics"
Course1	transfer, online, lecture, studio	Type of first-semester introductory course
Course2	transfer, online, lecture, studio	Type of second-semester introductory course
Gender	male = 0, diverse = 0.5, female = 1	Gender
Grade1st	nonpassing = 0 – best = 4	Grade in first-semester introductory course
Grade2nd	nonpassing = 0 – best = 4	Grade in second-semester introductory course
Grade3rd	nonpassing = 0 – best = 4	Grade in third, subsequent course
HelpLabRec	NO! = 0 – YES! = 3; N/A	"I was able to help my classmates with physics in the laboratory or recitation attached to this course"
InterPhys	very boring = 0 – very interesting = 3	"In general, I find physics […]"
KnowPhys	NO! = 0 – YES! = 3	"I want to know everything I can about physics"
Lecture	0–2	Number of lecture-based introductory courses taken (see Table IV)
OcSetbcks	NO! = 0 – YES! = 3	"If I encounter a setback in a physics exam, I can overcome it"
Online	0–2	Number of online introductory courses taken (see Table IV)
Prep	NO! = 0 – YES! = 3	"Did you feel that your previous physics courses prepared you well for this course?"
PrepProbSolve	not at all = 0 – very = 3	"How helpful were your previous physics courses for this course in terms of methods and problem solving?"
PrepTopics	not at all = 0 – very = 3	"How helpful were your previous physics courses for this course in terms of topic coverage?"
RecDiscs	NO! = 0 – YES! = 3	"I am curious about recent discoveries in physics"
Studio	0–2	Number of studio-based introductory courses taken (see Table IV)
TestIfStudy	NO! = 0 – YES! = 3	"If I study, I will do well on a physics test"
WonderPhys	NO! = 0 – YES! = 3	"I wonder about how physics works"

B. Gender

Of the respondents who completely filled out the survey, 65 identified as male, 38 as female, and 1 as diverse. While women were underrepresented by almost 2∶1, they were overrepresented in this sample of physics and engineering majors.

Female students achieved slightly higher average grades than their male counterparts in all three semesters, with 4.0 being the best grade, female students had average grade of 3.7 ± 0.5, 3.7 ± 0.4, and 3.7 ± 0.5 for the first, second, and third course, respectively, compared to 3.5 ± 0.6, 3.5 ± 0.7, and 3.4 ± 0.7 for the male students. These differences in averages, however, are statistically not significant.

In contrast to several other studies, most self-efficacy and all preparedness variables were almost identical between male and female students, with the notable but still not statistically significant exception of *InterPhys*, which had an average of 2.1 ± 0.5 for female versus 2.5 ± 0.5 for male students.

C. Course types

Table II shows the types of courses that students took in the first semester in its rows and the courses they took in the second semester in its columns. For students who had AP credit and transfer credit from another institution, the instructional mode is listed as "Unknown." While both online and lecture-based courses lost enrollments from the first to the second semester, studio-based physics gained enrollment.

With very few exceptions listed in Table III, there are no significant correlations at the $p < 0.05$ level between any of the variables in Table I and switching from one type of course to another. Most notably, switching into or staying in studio-format courses was positively correlated with measures of self-efficacy in overcoming obstacles and feeling prepared.

Table IV shows the introductory physics courses taken by the respondents who filled out the complete survey. Of these 104 respondents, 74 subsequently attended a third-semester physics or engineering course that included laboratory or recitation components (*LabRecCourse3*), and 30 students took a subsequent physics course (*PhysicsCourse3*). Not surprisingly, all self-efficacy variables were higher for physics than for engineering majors, however, only KnowPhys (2.7 ± 0.5 for physics versus 2.0 ± 0.8 for engineering) and *InterPhys* (2.7 ± 0.5 for physics versus 2.3 ± 0.5 for engineering) came close to statistical significance. Overall, though, differences between majors were higher than differences between genders.

TABLE II. Types of courses taken by the respondents in the first semester (rows) and second semester (columns).

	Unknown	Online	Lecture	Studio	Σ
Unknown	6	1	2	3	12
Online	0	6	13	3	22
Lecture	4	5	29	18	56
Studio	1	1	7	8	17
Σ	11	13	51	32	107

TABLE III. Significant correlations between switching course types and the variables in Table I. Shown are the correlation coefficients r, the effect sizes r^2, and the probability values p.

Switching	Variable	r-coefficient	r^2	p-value
… out of Online	*Grade1*	−0.21	0.04	0.03
… out of Online	*Grade2*	−0.23	0.05	0.02
… into Lecture	*Grade2*	−0.37	0.14	0.0001
… into Lecture	*Gender*	−0.24	0.06	0.02
… out of Studio	*TestIfStudy*	−0.22	0.05	0.04
… into Studio	*OcSetbcks*	0.71	0.50	0.05
… into Studio	*Prep*	0.9	0.81	0.01
Stayed in Studio	*OcSetbcks*	0.23	0.05	0.02
Stayed in Studio	*Prep*	0.11	0.01	0.04
Stayed in Studio	*PrepProbSolve*	0.2	0.04	0.03

TABLE IV. Types of courses taken by the respondents who completely filled out the survey ($n = 104$), which determine the value of the attributes *Online*, *Lecture*, and *Studio*. As an example, 21 respondents would have a value of $Online = 1$, and 6 respondents a value of $Online = 2$.

Course type	Only one semester	Both semesters
Unknown	11	6
Online	21	6
Lecture	47	29
Studio	33	7

D. Correlations of attributes

Figures 1 and 2 show the correlations between the variables in Table I as a force-directed Fruchterman-Reingold graph [45,46,48]. The vertices denote the variables in Table I. Green edges denote positive correlations, while red edges denote negative ones; the thickness and saturation of these edges denote the correlation strength. The distance between the vertices is determined by three sets of forces: a general repulsive force between the vertices, a central force to keep the vertices from drifting apart, and pairwise attractive forces that increase with the absolute value of the correlation [49]. Thus, mutually closely correlated or anticorrelated vertices tend to cluster together, while unrelated vertices are farther apart. The rotation and handedness of the graphs are random.

As shown in Table I, *Gender* was coded male = 0, diverse = 0.5, and female = 1; thus, if an attribute has a positive correlation with *Gender*, it means that it tends to have a higher value for female students. Figure 1 shows this

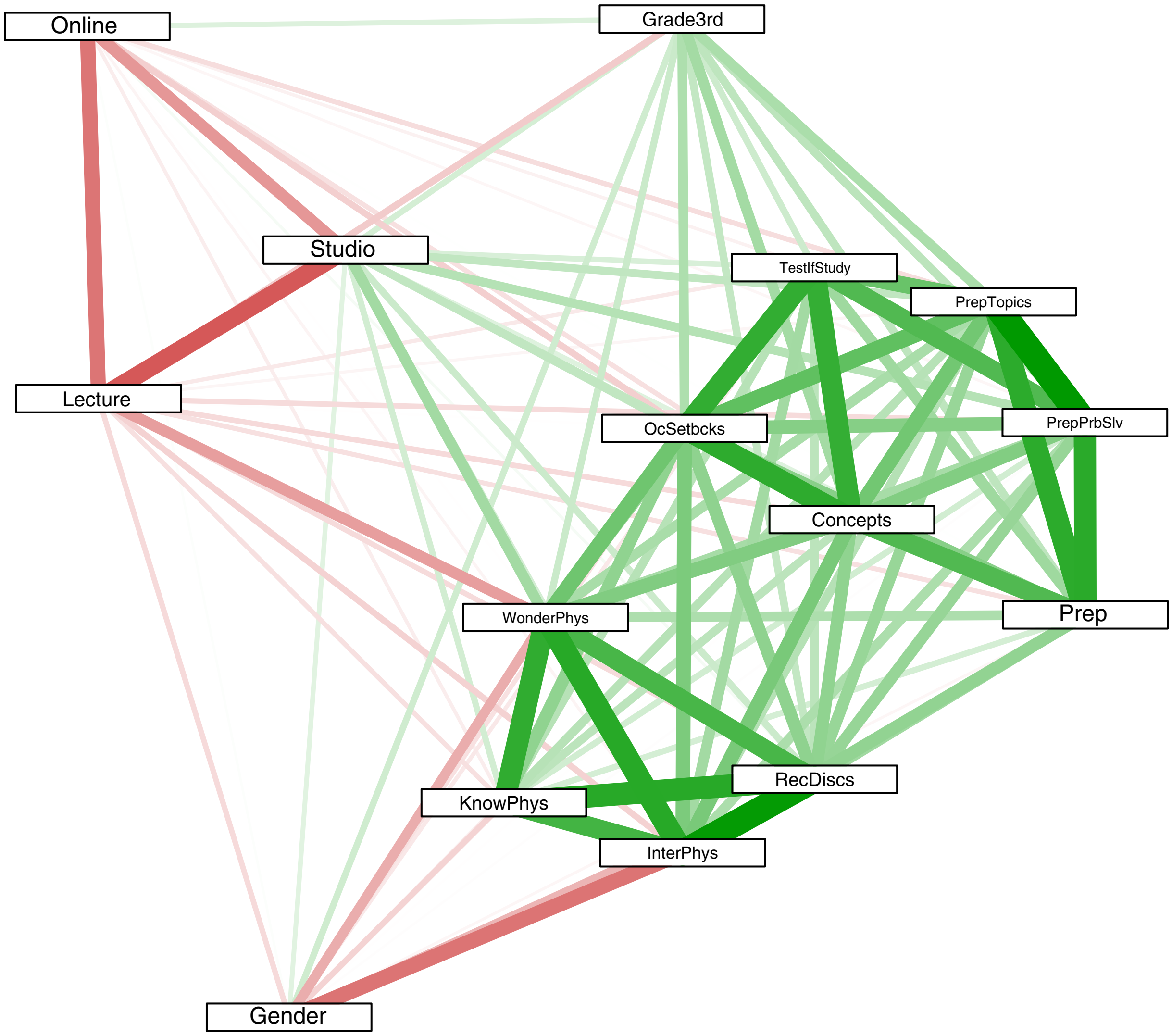

FIG. 1. Fruchterman-Reingold representation [46,48] of the correlations between a subset of the survey variables (Table I, excluding HelpLabRec) for any subsequent courses (AnyCourse3, 104 respondents).

for *AnyCourse3*, while Fig. 2 only considers the subsample *RecLabCourse3* and includes the *HelpLabRec* vertex.

While Figs. 1 and 2 reflect trends in our sample and subsamples, not all of these correlations are significant and not all of them are interesting. The negative correlations between the introductory course types are trivial, and the positive correlations between several of the attributes are hardly surprising. Table V lists the nontrivial significant correlations between *Online*, *Lecture*, *Studio*, and *Gender*, and other attributes [47].

It turns out that none of the variables are significantly correlated with course grades, and none were found for having attended the online courses. Instead, significant correlations emerged between a number of other variables: lecture courses were less frequently selected by students expressing curiosity about physics (*WonderPhys*; $r = -0.27$, $p = 0.005$), and they were also less frequently selected by female students who later moved on to more advanced physics courses ($r = -0.49$, $p = 0.006$). Studio physics on the other hand was positively correlated with curiosity about physics ($r = 0.26$, $p = 0.008$) and the feeling of preparedness for future courses, particularly in the area of problem solving (*PrepPrbSlv*; $r = 0.21$, $p = 0.03$). Sadly, the most significant correlation ($p < 0.0001$) is a negative one between *Gender* and interest in physics; fortunately, the effect size is small ($r^2 = 0.15$).

E. Grade in third course based on attributes

Notably, in Table V, for neither the sample nor any of the subsamples, significant correlations ($p < 0.05$) could be found between the introductory course types (*Online*, *Lecture*, or *Studio*) and the grade in the subsequent course (*Grade3rd*); this was confirmed by a multiple linear

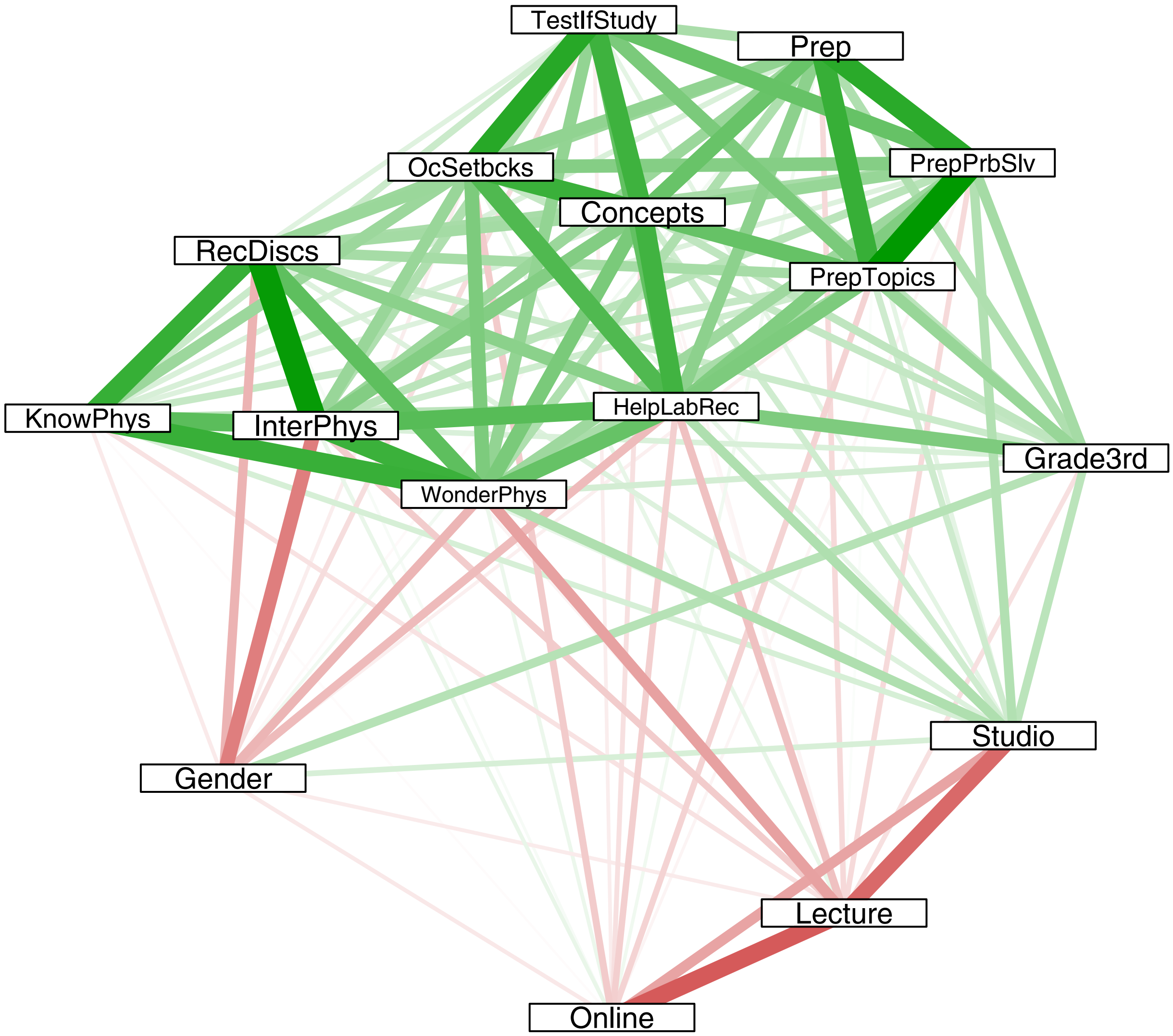

FIG. 2. Fruchterman-Reingold representation [46,48] of the correlations between a subset of the survey variables (Table I, including HelpLabRec) for subsequent courses that had laboratory or recitations components (LabRecCourse3, 74 respondents).

regression, which also showed no significance of the type of course for the grade in the subsequent course. In fact, a multiple linear regression only resulted in any significant relationships for the subsample *LabRegCourse3*, see Table VI ($R^2 = 0.38$), but neither for the full sample nor any other subsamples.

For the subsample *LabRecCourse*, feeling able to help in laboratory and recitation settings (*HelpLabRec*) has the most significant impact on the grade in the third course ($r = 0.38$, $p \approx 0.0004$), followed by interest in physics (*InterPhys*, $r = -0.49$, $p \approx 0.02$) and female students doing better (*Gender*, $r = 0.33$, $p \approx 0.04$). The negative sign of the correlation with *InterPhys* in this multiple linear regression is distressing; it is related to women doing better in terms of physics grades in spite of having less interest in the subject (in fact, when removing *Gender* from consideration, the negative correlation becomes even stronger, $r = -0.62$, $p \approx 0.004$, since then *InterPhys* carries all of the gender effects). Even within this subsample, the other attributes had no significant correlation, including the course type.

F. Correlation between grades

Figure 3 shows the correlation between grades in introductory online, lecture, or studio courses and subsequent third courses. It turns out that the predictive power of the grades in introductory courses is low ($R^2 = 0.12$ for online, $R^2 = 0.21$ for lecture, and $R^2 = 0.32$ for studio courses; with R^2 being interpreted as the proportion of the variance that can be explained, across course types, less than one third of the grade in later courses is explained by the earlier grade). Considering only the subsample of students with subsequent advanced physics courses (*PhysicsCourse3*), the predictive power is slightly higher for the online grades but lower for the lecture or studio

TABLE V. Significant correlations between attributes in Table I. Shown are the correlation coefficients r, the effect sizes r^2, and the probability values p.

Attribute 1	Attribute 2	Sample/Subsample	r coefficient	r^2	p value
Lecture	*WonderPhys*	*AnyCourse3*	−0.27	0.07	0.005
Lecture	*WonderPhys*	*LabRegCourse3*	−0.28	0.08	0.02
Lecture	*Gender*	*PhysicsCourse3*	−0.49	0.24	0.006
Studio	*OcSetbcks*	*NoLabRecCourse3*	0.36	0.13	0.05
Studio	*WonderPhys*	*AnyCourse3*	0.26	0.07	0.008
Studio	*WonderPhys*	*LabRegCourse3*	0.23	0.05	0.04
Studio	*PrepPrbSlv*	*AnyCourse3*	0.21	0.04	0.03
Studio	*PrepPrbSlv*	*LabRegCourse3*	0.23	0.05	0.05
Studio	*HelpLabRec*	*LabRegCourse3*	0.24	0.06	0.04
Gender	*WonderPhys*	*AnyCourse3*	−0.23	0.05	0.02
Gender	*RecDiscs*	*AnyCourse3*	−0.21	0.04	0.03
Gender	*InterPhys*	*AnyCourse3*	−0.39	0.15	0.00004
Gender	*InterPhys*	*NoLabRecCourse3*	−0.44	0.19	0.01
Gender	*InterPhys*	*LabRegCourse3*	−0.38	0.14	0.0009
Gender	*InterPhys*	*PhysicsCourse3*	−0.46	0.21	0.01

grades ($R^2 = 0.27$ for online, $R^2 = 0.09$ for lecture, and $R^2 = 0.26$ for studio courses).

V. DISCUSSION

It was found earlier that having attended introductory physics in a studio setting had generally no significant impact on subsequent grades, compared to lecture settings [41]; it is thus not surprising that no significant effect on future grades could be found in this study. However, a grade-focused view of courses neglects less tangible goals of courses, such as instilling curiosity and interest, as well as increased self-efficacy; we found that studio-based courses are correlated with those desirable attributes. This is also true for switching to a studio section after the first semester in a different course setting. One needs to be careful, though, that these findings do not allow for establishing causal relationships.

TABLE VI. Multiple linear regression for the prediction of the grade in the third course, based on the attributes in Table I, for the subsample *LabRegCourse3* ($R^2 = 0.38$).

Attribute	r coefficient	Std. Err.	t value	p value
Online	0.24	0.16	1.53	0.132
Lecture	0.17	0.15	1.15	0.254
Studio	0.21	0.17	1.25	0.218
Concepts	−0.12	0.14	−0.87	0.390
TestIfStudy	0.15	0.13	1.17	0.246
OcSetbcks	−0.13	0.12	−1.11	0.271
WonderPhys	0.04	0.13	0.35	0.730
KnowPhys	0.02	0.12	0.13	0.894
RecDiscs	0.24	0.14	1.77	0.0813
InterPhys	−0.49	0.21	−2.34	0.0226
Prep	0.09	0.11	0.84	0.403
PrepPrbSlv	−0.10	0.12	−0.79	0.430
PrepTopics	0.10	0.12	0.83	0.409
Gender	0.33	0.15	2.15	0.0359
HelpLabRec	0.38	0.10	3.76	0.000395

As in several previous studies, women were in the minority in the courses under investigation (though, compared to the course populations, overrepresented in our sample), but as opposed to several earlier studies, women outperformed men in terms of grades (not significantly so, but generally across the sample). The subsequent courses taken into consideration in this study would be taken by STEM majors. It is surprising that even in this population, which would arguably have an affinity to science and math and probably identify as a "STEM-person," female students express significantly less interest in physics than their male counterparts. The finding is even more distressing given that women achieved higher physics grades than men, however, it aligns with earlier studies regarding interest in physics [50]. In other words, women succeeded in getting better grades than men in spite of professing less interest in the subject, which hints toward a stronger focus on grades [12], higher diligence [51,52], or seeing the study of physics simply as a means-to-an-end regarding future studies or career [53]. It had been found earlier that women sometimes have lower self-efficacy even when they have higher performance in engineering and mathematics courses [32]. It should also be noted that our survey took place after the introductory course sequence was completed, and there are indications that loss of initial interest in physics particularly among women can be the result of these courses [54].

We did not observe the statistically significant preference of women to select studio-based courses found earlier [55], but we did find a preference away from lecture-based courses (of course, this study has a third course mode, online, as a choice, making a significant trend away from

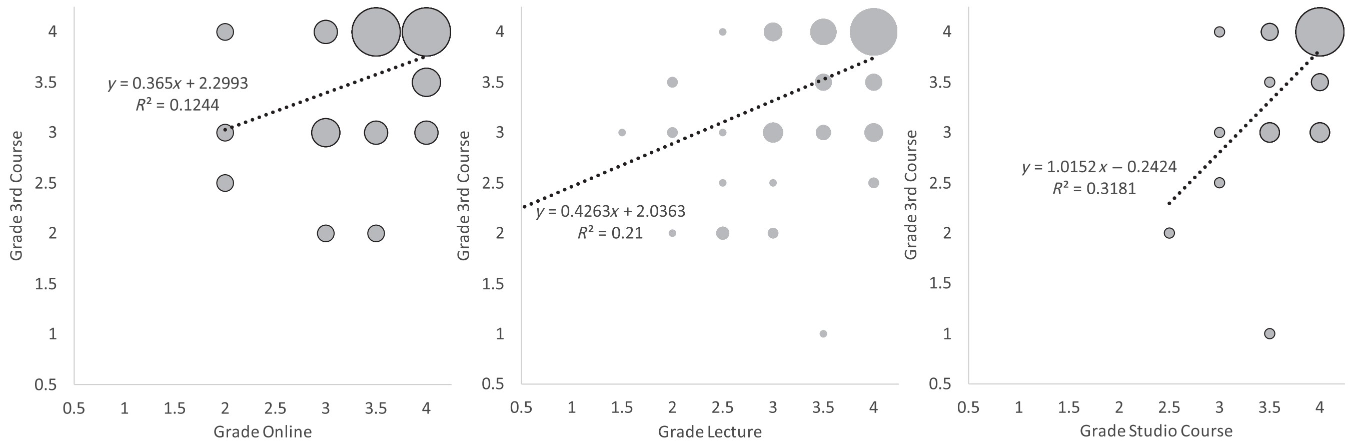

FIG. 3. Correlations between the grades in different types of introductory first-semester (*Grade1st*) and second-semester (*Grade2nd*) courses and the grade in the subsequent course (*Grade3rd*). Considered were all 107 survey responses, even if other fields were left blank; removed were three responses that listed the grade in the third course as 0.0, which would translate into the student not passing the third course for any number of possible reasons. The left panel shows the correlation for Online courses ($n = 35$), the middle panel for Lecture courses ($n = 103$), and the right panel for Studio courses ($n = 46$). The area of the markers is proportional to the number of respondents with the respective combination of grades.

one option not necessarily a significant trend toward one particular other one).

Online courses are much more scalable than lecture-based courses, which in turn require significantly less personnel resources than studio-based courses. While a null result technically is no result, the lack of significant findings is consistent with the literature [1–5]. Given that we only find very slight differences in success in subsequent courses between the three teaching modes, one has to ask if an allocation of significant additional teaching personnel is justifiable [56]. Arguably, possible differences may have been masked by the fact that students were not assigned to different course types in a controlled experiment [3]; instead, which course type they attended may have been determined by a variety of preferences, constraints, instructor reputation, and informed or uninformed decisions.

The survey would have greatly benefitted from a free-response field asking students why they chose the course types they did; since only very few significant correlations were found, and in any case, those do not allow for establishing causal relationships, any readers interested in replicating the study might want to add such a field to the survey [44]. Also, in retrospect, our method of data collection was unnecessarily cumbersome, which may have led to a response rate that was lower than we had hoped for. For privacy reasons, we did not have access to enrollment lists for the higher-semester courses, so department and college administrators (who have access) were asked to email the students. This mechanism had been approved by our Institutional Review Board. It is, however, our suspicion that emails by administrators are routinely ignored by students, and there was no personal connection or accountability for students to take notice. Instead, for possible future replications of this type of study, a more promising approach might be to ask and authorize the instructors of the second-semester introductory physics courses to email their own former students one semester or one year later; students would hopefully still recognize the name of their instructors in their inbox. In addition, a raffle of some sort might have increased the response rate, as well as enlisting the help of the third-semester instructors for advertising the survey.

VI. LIMITATIONS

While the survey was distributed to over a thousand students, only 104 students provided valid responses. There may well have been a selection bias toward the more motivated, engaged students. Also, not finding significant correlations within this sample does not mean that there are none within the full population. Finally, it should be emphasized that we investigated studio, lecture, and online courses at one particular university; at other universities, different implementations of these formats might lead to significant differences.

VII. CONCLUSION

Overall, we found that the mode of instruction of an introductory, calculus-based physics sequence generally has no significant influence on grades at the end of a subsequent engineering or more advanced physics course. However, in particular combinations, there was a retained effect on self-efficacy and interest in physics: students who were enrolled in introductory studio-physics courses felt better prepared for the subsequent courses, particularly those that included laboratory or recitation components. Studio classes were also significantly positively correlated with wondering how physics works, while lecture-based courses had a negative correlation with this measure of curiosity about physics.

While female students received slightly but not significantly better grades in all three courses (introductory and subsequent), they generally expressed significantly less interest in physics. In terms of preferred learning scenarios, female students who later took advanced physics courses were less likely to have selected lecture-based introductory physics courses.

None of the nontrivial significant correlations between any of the variables and none of the regression coefficients for grades in future courses involve participation in online courses. This null result opens up questions regarding the best allocation of teaching resources.

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