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RESEARCH ARTICLE

Analyzing the impact of basic psychological needs on student academic performance: a comparison of post-pandemic interactive synchronous hyflex and pre-pandemic traditional face-to-face instruction

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Abstract
During COVID, HyFlex gained popularity and became a "new normal" that educators need to consider as an effective instructional approach. Previous research offers conflicting findings related to the impact of HyFlex instruction on students' basic psychological needs and academic performance. Our investigation provides insight into a specific variation of HyFlex we call "Interactive Synchronous HyFlex" as it is situated in a highly collaborative active learning environment. The investigation aimed to clarify relationships between students' academic performance, basic psychological needs, and demographics of a pre-pandemic face-to-face offering of an undergraduate project-based design course and the same course using an Interactive Synchronous HyFlex approach at the end of the pandemic. Demographic data were collected from university databases; academic performance was measured by end-of-semester grades; and a survey measured basic psychological needs. The findings revealed that students in the HyFlex offering perceived their basic psychological needs as being met as effectively or significantly more so compared to students in the face-to-face offering. Significant predictors of student academic success were different for face-to-face environments compared to predictors that were significant in HyFlex environments. In the HyFlex environment, relatedness to the instructor was a significant predictor of academic success as was class rank and gender. These findings point to the importance of instructor presence as a key factor in student success in the HyFlex model. Overall, the results indicate that the HyFlex environment is a viable educational model for the post-pandemic era.

Keywords Design · First Year · Basic Psychological Needs · Academic performance · Grades · HyFlex · Design thinking education · Project based learning · Blended Learning

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Introduction

The creation of blended and online learning environments in higher education has been trending for several years to meet the ever changing needs of students (Alammary et al., 2014; Boelens et al., 2018; Crosling, 2023) and was accelerated by COVID-19. To protect public health and support students and instructors in quarantine, many universities rapidly adopted fully online and hybrid teaching and learning methods. Among these methods, HyFlex (Hybrid Flexible) was a widely implemented approach because of its advantages to instructors and students in teaching and learning processes (Mentzer & Mohandas, 2022; Padilla Rodriguez, 2022). HyFlex gives students autonomy to choose the mode of their lesson participation, either in person, synchronous online, or asynchronous, where course content is available at the students' convenience (Beatty, 2019; Lakhal et al., 2014).

HyFlex combines hybrid and flexible teaching and learning methods that allow students to choose their participation modality in the class, either synchronous online, asynchronous online, or face-to-face (Beatty, 2019). The HyFlex model started gaining popularity with higher education institutions to provide learning opportunities to people at any stage of their life, thereby expanding access to students who may not be able to get to campus (rural, geographically bound, or for a myriad of other reasons) (Raes et al., 2020). The benefits for universities to incorporate a HyFlex model include an increase in student enrollment, cost cuts, and efficient use of time and space. According to Beatty (2013), the main merits of HyFlex models include "(a) Student choice- gives students the choice in how they want to complete the course, (b) Equivalency providing equivalent learning opportunities in all participation modes, (c) Reusability- utilize artifacts from learning activities in each participation mode as learning objects for all students and d) Accessibility- equip students with technology skills and access to all participation modes" (pp. 157–158).

Not only does blending remote and face-to-face learners impact the process of learning, it may expand what is actually learned to include how to successfully navigate blending teamwork environments. The experience of blending by its very nature may better prepare future graduates for engaging in the global economy: "The contemporary workplace needs digitally savvy employees who can conduct their work effectively and seamlessly through constantly updating technologies and emerging media" (Blau et al., 2020, p. 2). According to the twenty-first century workforce requirements, universities should focus on providing graduates with knowledge and skills to meet industry demands, which include tackling an uncertain future ahead to meet students' changing needs (Barnett, 2004; Norton & Cakitaki, 2016; Oliver, 2015; Qenani et al., 2014).

In this study, we examined the impact of a specific version of HyFlex on students' academic performance and basic psychological needs (BPN) in an introductory design thinking course. Our model, Interactive Synchronous HyFlex, allows students to join class sessions remotely or face-to-face on any given day without prior arrangements and facilitates synchronous active interaction between students physically in class and those who might be remote. Hence, we compared sections taught traditionally (Fall and Spring of 2019) to the same course offered as Interactive Synchronous HyFlex instruction (Fall of 2022 and Spring of 2023) near the end of the pandemic when the World Health Organization declared the pandemic a non-emergency internationally ("World Health Organization statement on COVID-19," 2023) and academic disruption was minimal. By analyzing BPN scores and students' final course grades, we investigated the possibility of our model being feasible for the post-pandemic era in higher education.

Background literature

Although HyFlex can facilitate supportive and inclusive environments that boost student satisfaction and engagement (Calafiore & Giudici, 2021; Lakhal et al., 2014; Magana et al., 2022), the effectiveness of this model in supporting students' academic success is unclear. Traditionally, grades have been used as a measurement of students' academic performance (Johnston & O'Neill, 1973; Sadler, 2009; York et al., 2015), but previous research considering the impact of HyFlex approaches have on course grades suggest conflicting results, with some research indicating that there was no significant differences across face-to-face and HyFlex (Lakhal et al., 2014; Magana et al., 2022; Miller et al., 2013; Rhoads, 2020). Other research suggested that grades (Calafiore & Giudici, 2021) or mean rank of grades (Mentzer et al., 2023a, 2023b) were significantly higher or lower (He et al., 2015) in HyFlex environments as compared to traditional environments.

Beyond grades, students' perceptions of the extent their basic psychological needs are being met can offer insight into the overall success of a learning environment (Badri et al., 2014; Buzzai et al., 2021; Carmona-Halty et al., 2019). A few studies have examined the impact of HyFlex instruction on students' basic psychological needs (BPN) by measuring autonomy, competence, and relatedness (Bozan et al., 2023; Holzer et al., 2021; Mentzer et al., 2023a, 2023b) and reported contradictory results. Further complicating understanding the impact of HyFlex on BPN, these studies analyzed data collected in 2020, when the pandemic caused severe disruptions in education, potentially limiting generalizability. Therefore, exploring the impact of HyFlex instruction on students' BPN in the post-pandemic era is needed to define whether the instruction is practical in the "new normal."

Regardless of students' participation mode, HyFlex offers face-to-face and remote students options to listen to a live presentation and interact with peers simultaneously (Heilporn & Lakhal, 2021; Lakhal et al., 2017). It also offers students the potential for interaction with lesson content online asynchronously by watching online video recordings (Heilporn & Lakhal, 2021) and communicating with peers through discussion forums (Lakhal et al., 2014). Additionally, participating remotely in a HyFlex environment may minimize distractions and create a safe zone for students, giving them greater control over their surroundings (Mentzer et al., 2023a, 2023b). While comparing the effect of hybrid flexible and traditional course delivery modes, Lightner and Lightner-Laws (2016) asserted that the course delivery mode can significantly and positively affect students' academic performance as measured by increased passing rates. During the pandemic, this model emerged as a flexible and practical approach to teaching and learning by empowering students to choose their preferred mode of participation and offering options for engaging with course content and peers.

Final course grade as an indicator of academic performance

Despite the benefits, the impact of HyFlex instruction on student academic performance raises questions among researchers due to the wide range of results. For example, Magana et al. (2022) compared students' grades for four team-project-based assignments, described as Milestones, in traditional and HyFlex semesters. Overall, students' academic performance did not differ significantly in traditional and HyFlex course delivery modes ($U = 6777$, $p = 0.512$). However, when the researchers analyzed projects in detail, they found a significant difference in students' team academic performance for Milestone 2

($U = 189$, $p < 0.05$), where students' score was higher in HyFlex compared to traditional course delivery mode. Further, students' individual academic performance on the second term exam between traditional and HyFlex modes were similar ($H = 3.860$, $p = 0.45$). Comparing student performance on design projects, Mentzer et al., (2023a, 2023b) found that while mean scores were similar, the mean rank of each project grade was significantly higher in Interactive Synchronous HyFlex instruction than in traditional offering. Though non-parametric analysis indicated grades were higher, the broader distribution of project grades in Interactive Synchronous HyFlex instruction was concerning, with a greater number of high and low grades than in a face-to-face-only approach.

Research by He et al. (2015) indicated that students' grades in HyFlex mode were lower than those in traditional face-to-face classes. On the contrary, Calafiore and Giudici (2021) found that non-traditional students' course letter grades in the HyFlex ($n = 58$, $M = 2.362$) were higher compared to the hybrid course, which blended face-to-face synchronous and asynchronous online learning ($n = 63$, $M = 1.937$). Students in their study were non-traditional, household leaders, working full-time, with an average age of 31, which may not be generalizable to other student groups.

Self-determination theory: basic psychological needs

Due to evidence that HyFlex generally supports autonomy and relatedness for meeting the needs and preferences of a diverse group of students, HyFlex can potentially become the new standard (Dziuban et al., 2018; Norberg et al., 2011) to foster a supportive and welcoming inclusive environment in higher education. Shuetz (2008) implemented a mixed methods study and reported that Self-Determination Theory (SDT) effectively explained the driving forces behind successfully engaging students in learning, where the crucial motivators are competency, autonomy, and relatedness. SDT is a methodological approach to motivation that emphasizes the importance of personality development and behavioral self-regulation (Ryan & Deci, 2017). People's inclination for growth and personal motivation is driven by basic psychological needs—the need for autonomy, competency, and relatedness (Deci & Ryan, 2012). In a learning environment, autonomy refers to learners' freedom of choice, competency is one's capability to fulfill learning expectations (Levesque-Bristol et al., 2010), and relatedness is the feeling of connectedness the learner has to their peers and instructor (Fedesco et al., 2019). Limited research has examined how HyFlex impacts students' basic psychological needs, including autonomy, competence, and relatedness. Holzer et al. (2021) found that online or HyFlex course instruction had a negative impact on relatedness and a positive impact on autonomy and competence. Bozan et al. (2023) reported a higher level of competence and relatedness satisfaction with a marginal increase in autonomy satisfaction in HyFlex and online environments. Mentzer et al., (2023a, 2023b) reported significantly lower autonomy frustration and competence frustration in Interactive Synchronous HyFlex compared to the traditional delivery mode of the same course. However, autonomy satisfaction, competence satisfaction, and relatedness levels were not significantly different for traditional and HyFlex delivery modes.

This study aimed to inform post-pandemic instruction by investigating the impact of HyFlex on course grades and students' basic psychological needs. The research team, comprised of the course coordinators, a member of the University Instructional Excellence team and a learning design and technology researcher, were motivated by the conflicting literature surrounding HyFlex and investigated the HyFlex approach in a large active

learning problem-based course in the last two semesters of the pandemic when the academic environment was quickly returning to normal. Analysis in this study controlled for demographic characteristics and used these variables as predictors to help explain variation in previous studies. Our study provides insights about various student subgroups, including class rank and underrepresented groups in science, technology, engineering, and mathematics (STEM) education (O'Brien et al., 2015). We analyzed undergraduate students' academic performance and basic psychological needs in traditional and Interactive Synchronous HyFlex instruction in an introductory design course. Two **research questions** guided this study:

1. How does the Interactive Synchronous HyFlex course design meet students' basic psychological needs in the post-pandemic era compared to a traditional face-to-face-only course delivery mode used before COVID-19?
2. How do basic psychological needs and demographic variables influence students' academic performance in Interactive Synchronous HyFlex and traditional course delivery modes?

Methods

Participants

The study utilized data from 2558 undergraduate students (1931 males and 555 females) enrolled in the same introductory design course required for all technology undergraduate students at a large Midwestern university. Participants in all sections of this course used for this study had the same academic learning outcomes, the same content, assessments and rubrics regardless of the modality (face-to-face only or HyFlex). The average age was 19.1 (SD = 1.8). Most participants were from the U.S. by residency (n = 2208; 86.3%), while 10.9% (n = 279) were international. A majority of participants were in their first year by credit hour (n = 1144; 44.8%), followed by sophomores (n = 841; 32.9%), juniors (n = 358; 14%), and seniors (n = 143; 5.6%).

In total, students' ethnicity consisted of nine groups, where international students 10.9% (n = 279) were classified as international regardless of ethnicity. Most of the domestic participants were White (n = 1583; 61.9%), 9% Asian American (n = 230), followed by Hispanic/Latino (n = 176; 6.9%), unknown (n = 111; 4.3%), 2 or more races (n = 109; 4.3%), Black or African American (n = 67; 2.6%), Native Hawaiian or Other Pacific Islander (n = 2; 0.1%) and one student was American Indian or Alaska Native. Participant average SAT score was 1253.70 (SD = 133.11) out of 1600 maximum, while the average final course grade was 90.41% (SD = 10.74) with a maximum of 104.62% due to extra credit opportunities. All data were collected with the approval of Purdue University's Institutional Review Board (IRB).

Setting

The course focuses on key design thinking processes, including problem definition, brainstorming, benchmarking, decision-making, prototyping, and communicating results. Students engaged in three design projects through the semester. The first was brief, where they were challenged to uncover an opportunity to optimize a peer's college experience by

investigating, for example, their time management strategies and suggesting solutions. In the second project, students engaged in teams to identify a problem within their major and develop a conceptual solution, such as, noise pollution at the airport for aviation majors. In the third project, students worked in self-selected multidisciplinary teams to tackle a grand challenge such as clean water in our local area. They developed a functional prototype as a proof of concept. Each project was evaluated heavily on the process as opposed to the product. Most of the individual assignments are directly related to the three larger collaborative learning projects where students worked in pairs or small groups of 3–5. This active learning course was highly interactive such that students received only brief orientation at the start of class by the instructor to prime them for collaborative class work. Think pair share, project work time, reflection, and report out were key pedagogical strategies.

The course was facilitated through small sections consisting of approximately 36–40 students each, situated in a classroom environment with moveable chairs and small group work tables, individual whiteboards for each team, and access to personal devices (e.g., laptops, tablets). Most students enrolled in the course were in their first year of college. Students attended class twice a week, each lasting 50 min. Graduate students, either former technology and engineering education teachers or prospective university faculty, typically instruct the course with the support of two coordinators, one senior lecturer and one faculty member. To provide continuity among the multiple sections of the course and across semesters, the course coordinators (one of which is a current instructor of a few sections per semester and one was a previous instructor) provided a shell in Brightspace (the course LMS) that contains all student facing materials, assignments and grading criteria and an extensive teaching implementation plan document that covers course policy, daily lessons and other relevant instructor facing details. Before classes started and throughout the semester, the coordinators provided professional development to the instructors during weekly two-hour meetings. The instructional team was generally consistent for the duration of the study with a few new instructors being hired each year to replace graduating instructors. Once hired, instructors tended to stay for the duration of their graduate program which was typically 2–5 years.

Before the pandemic, the course was taught in a traditional face-to-face-only format, where face-to-face attendance was mandatory for all students. However, since the Spring 2020, due to COVID-19 restrictions, the course has been offered in the Interactive Synchronous HyFlex format, where participation may be face-to-face or synchronous online. We coined the term "Interactive Synchronous HyFlex" to clarify that our course was active learning and required interactions between students within teams, across teams and between instructors and students. Thus, our course required students to be interactive and we expected students to participate synchronously to facilitate interaction among students physically present and those participating remotely. Our design was intentional in that we recognized on any given day, with little to no warning, a student may need to be remote, and we sought to facilitate their uninterrupted live interaction with peers and their instructor just as if they were in the room.

The most significant change to the course as we transitioned from face-to-face only to HyFlex was the addition of Microsoft Teams which was used as a primary method of communication between instructors and peers. A Microsoft Teams meeting was started at the start of each class session and students were instructed to join with their cameras on and mics muted. The Microsoft Teams general channel mirrored the classroom and small group channels were created for each small group in the classroom to facilitate their table level collaborations. Within the HyFlex course delivery mode, dedicated virtual office hours were offered to students to facilitate direct interaction between students and instructors.

To enhance accessibility, instructors offered links for booking one-on-one meetings with students, which allowed both parties to schedule meetings at mutually convenient times, promoting individual interaction and support within the course structure. In addition to virtual office hours, instructors actively utilized the chat feature within Microsoft Teams that provided students with immediate assistance by initiating text-based conversations with their instructors.

To investigate the relationship between the two teaching and learning modes, students' academic performance and BPN, this study considered Fall 2022 and Spring 2023 as the treatment semesters. Given the shift from in-person instruction to online teaching due to the pandemic in Spring of 2020, we selected two semesters just prior to COVID-19: Fall and Spring of 2019 as a traditional course delivery mode for comparison. As this course is predominantly a first-year student course, with most students entering the university in the fall semester, differences between fall and spring were anticipated and controlled for statistically. The study employed a quasi-experimental design using a pretest method with non-equivalent groups. This design used Scholastic Assessment Test (SAT) scores as a proxy pre-test to indicate that the groups were academically similar prior to analysis. Analysis in this study was performed using Statistical Package for Social Sciences (SPSS; IBM SPSS Statistics, Version 29.0) software program.

Data sources

Final course grade (dependent variable)

Total final course grades were cumulative throughout the semester based on students' assignment submissions, quizzes, and group projects. Graduate student graders were calibrated and manually graded assignments and group projects following assignment-specific rubrics, which account for the vast majority of course credit. A small part of the course grade was determined by quizzes that were calculated automatically. Students' final course grade was calculated as a percentage of the maximum possible grade, obtained by dividing each student's actual final grade by the highest possible grade. Due to the large sample size ($n = 2558$), a Kolmogorov-Smirnova test was run to test for the normality of the final course grade distribution per semester. The results indicated a significant deviation from a normal distribution. However, the central limit theorem diminishes the significance of deviations from normality when larger sample sizes are employed and supports the robustness of statistical analyses (Kamis & Lynch, 2020; Kwak & Kim, 2017); hence, we acknowledge the non-normal distribution while interpreting our analysis using parametric statistical analysis.

Basic psychological needs

The Basic Psychological Needs Scale (BPNS) is an instrument used to measure BPN based on the Basic Psychological Needs Theory (Deci & Ryan, 2000). The Center for Instructional Excellence at Purdue University adapted the BPNS as a university wide measure of instructional excellence and provided access to the results for our analysis (Levesque-Bristol, et al., 2019). The survey evolved during the study from six subscales to four: autonomy satisfaction (4 items), competence satisfaction (4 items), relatedness to instructors (3 items), and relatedness to peers (3 items). Prior to the pandemic, the Center had administered the survey with two constructs related to frustration (of

autonomy and competence) and two additional questions related to frustration for each relatedness measure. The Center concluded that student satisfaction measures were sufficiently reliable and informative, which is why the frustration items were no longer measured (Fedesco et al., 2019; Wang et al., 2019). This decision was supported by the studies that questioned the validity of Basic Psychological Need Satisfaction and Frustration Scales as a measure of need frustration (Murphy et al., 2023). We assert that the means of these scores are comparable for our study because they measure the same construct with a more parsimonious set of questions. A Likert-type scale ranging from strongly agree to strongly disagree was used to measure all items on a 7-point scale.

The BPNS survey was distributed to students a few weeks before the end of the course. Survey completion was voluntary, with students having ten days to participate and receiving extra credit (valued at 1% of the course grade), resulting in usable data on BPN from 1,203 students. Since the Center modified the survey to be more reliable and informative during the HyFlex semesters, we ran a Cronbach alpha analysis to confirm the reliability of the survey instrument further. As shown in Table 1, Cronbach alpha is above 0.7 for all subscales, indicating that the items in each scale are sufficiently consistent and measure the same construct (Hair et al., 2013).

SAT scores as a pre-analysis similarity check

The SAT scores were collected from the University's application database and used as a proxy pre-test to ensure the student groups were similar before the treatment experiences. As most students in the course were in their first year, the SAT was a reasonable measure of academic preparation and similarities between groups. The research team used published concordance tables (The College Board, 2009) to convert previous SAT and ACT scores to equivalent current SAT scores. If a student took multiple exams, the highest SAT or SAT equivalent score was used as the reference for the study. An independent samples *t*-test was run to measure whether students were academically similar before the course. The test result indicated that traditional ($M = 1247.87$, $SD = 125.34$) and HyFlex ($M = 1261.3$, $SD = 142.31$) course delivery modes were not significantly different from each other in Spring terms of 2019 and 2023, $t(1075) = -1.519$, $p = 0.129$, Cohen's $d = -0.094$ nor in the Fall terms of 2019 and 2022 $t(900.65) = -1.612$, $p = 0.107$, Cohen's $d = -0.104$.

Table 1 Reliability of survey results on basic psychological needs

Subconstruct	Number of questions	Number of students with complete data	Cronbach α reliability
Autonomy satisfaction	4	1203	.752
Competence satisfaction	4	1203	.747
Relatedness to instructor	3–5	1203	.756
Relatedness to peer	3–5	1203	.802
Overall	10–14	1203	.814

Demographic variables as a pre-analysis similarity check

The research team obtained demographic information from the university's application database, including gender, ethnicity, and residency. Gender information was binary: male or female. Ethnicity was reported for domestic students as one of seven categories and merged down to four categories for our analysis: (1) underrepresented minorities (Blacks or African American, Hispanic/Latinos, American Indians or Alaska Natives, Native Hawaiian/Other Pacific Islanders, and 2 or more races), (2) overrepresented (White, Asian American), (3) international students (Allen-Ramdial & Campbell, 2014; Estrada et al., 2011; National Center for Science & Engineering Statistics, 2019; United States Census Bureau, 2023), and (4) unknown. Participants who did not report their race or ethnicity were categorized under the "unknown" group. Residency was defined as domestic and foreign (which was the same as "international" in the ethnicity demographic). The survey defined class rank based on the number of credit hours each student had earned, including credits earned before enrolling at the university. This study categorized class rank into three groups: 0–29 credit hours, 30–59 credit hours, and 60 + credit hours. Pearson $\chi 2$ results for the demographic variables are described in Tables 2 and 3. To examine the relationship between demographic variables in traditional vs. HyFlex course delivery, we ran a chi-square test. The results in Tables 2 and 3 show a non-significant relationship between demographic variables and course delivery modes for spring and fall semesters.

Table 2 Result of Pearson $\chi 2$ of Demographics in the Spring 2019 (Traditional course delivery) and Spring 2023 (HyFlex course delivery)

Demographic Variable	Traditional course delivery (Spring 2019) Number of students (%)	HyFlex course delivery (Spring 2023) Number of students (%)	Pearson $\chi 2$
Gender			
Male	497 (76.5%)	474 (76.7%)	$\chi 2(1) = .010$ $p = .920$
Female	153 (23.5%)	144 (23.3%)	
Class Rank (by credit hours)			
0–29 credit hours	204 (31.4%)	223 (36.1%)	$\chi 2(2) = 5.257$ $p = .072$
30–59 credit hours	258 (39.7%)	248 (40.1%)	
60 + credit hours	188 (28.9%)	147 (23.8%)	
Ethnicity			
Domestic Underrepresented	84 (12.8%)	100 (16.2%)	$\chi 2(3) = 4.635$ $p = .201$
Domestic Overrepresented	497 (76%)	438 (70.9%)	
International	61 (9.3%)	69 (11.2%)	
Unknown	12 (1.8%)	11 (1.8%)	
Residency			
Domestic	589 (90.6%)	549 (88.8%)	$\chi 2(1) = 1.09$ $p = .296$
Foreign	61 (9.4%)	69 (11.2%)	

Table 3 Result of Pearson $\chi 2$ of Demographics in the Fall 2019 (Traditional course delivery) and Fall 2022 (HyFlex course delivery)

Demographic Variable	Traditional course delivery (Fall 2019) Number of students (%)	HyFlex course delivery (Fall 2022) Number of students (%)	Pearson $\chi 2$
Gender			
Male	484 (78.6%)	476 (79.1%)	$\chi 2(1) = .045$ $p = .831$
Female	132 (21.4%)	126 (20.9%)	
Class rank (by credit hours)			
0–29 credit hours	365 (59.3%)	352 (58.5%)	$\chi 2(2) = .366$ $p = .833$
30–59 credit hours	165 (26.8%)	170 (28.2%)	
60 + credit hours	86 (14%)	80 (13.3%)	
Ethnicity			
Domestic Underrepresented	77 (11.8%)	94 (14.9%)	$\chi 2(3) = 3.259$ $p = .353$
Domestic Overrepresented	460 (70.2%)	418 (66.2%)	
International	74 (11.3%)	75 (11.9%)	
Unknown	44 (6.7%)	44 (7%)	
Residency			
Domestic	542 (88%)	528 (87.7%)	$\chi 2(1) = .022$ $p = .881$
Foreign	74 (12%)	74 (12.3%)	

Results

Research question 1

To answer the first research question, independent samples t-tests were used where appropriate to analyze how the Interactive Synchronous HyFlex design meets students' basic psychological needs in a post-pandemic learning environment compared to a traditional face-to-face only course delivery mode prior to the pandemic. For comparisons where Leven's test indicated unequal variances, Welch's t-tests were used to account for variance heterogeneity. As shown in Table 4, the results of comparing spring semesters indicated that all four BPN scores were significantly higher for Interactive Synchronous HyFlex mode. In the fall semester comparison, the HyFlex scores were also higher than the traditional scores such that autonomy satisfaction and the relatedness measures were significantly higher while competence satisfaction was only marginally higher. Values of Cohen's d for BPN scores showed the effect sizes of the differences in fall semesters ranged from 0.247 to 0.553, indicating small and medium effects and for spring semesters, ranged from 0.187 to 0.519, indicating minimal, small, and medium effect sizes.

Table 4 Independent t-test results of BPNS scores in Traditional and HyFlex course delivery modes

Semester	Modality	*M*	*SD*	*t*	*df*	*p*	*d*
Autonomy satisfaction							
Fall	Traditional ($n = 373$)	4.54	1.25	−3.001	614	.003	−.247
	HyFlex ($n = 243$)	4.86	1.37				
Spring	Traditional ($n = 397$)	4.23	1.30	−3.306	585	.001	−.292
	HyFlex ($n = 190$)	4.62	1.40				
Competence satisfaction							
Fall	Traditional ($n = 373$)	5.39	1.07	−.643	614	.520	−.053
	HyFlex ($n = 243$)	5.45	1.17				
Spring	Traditional ($n = 397$)	5.23	1.13	−2.116	585	.035	−.187
	HyFlex ($n = 190$)	5.45	1.14				
Relatedness to instructor							
Fall	Traditional ($n = 373$)	5.24	1.05	−3.628	614	< .001	−.299
	HyFlex ($n = 243$)	5.57	1.19				
Spring	Traditional ($n = 397$)	4.85	1.07	−2.911	303.22*	.004	−.280
	HyFlex ($n = 190$)	5.18	1.37				
Relatedness to peer							
Fall	Traditional ($n = 373$)	4.91	.95	−6.530	469.92*	< .001	−.553
	HyFlex ($n = 243$)	5.47	1.08				
Spring	Traditional ($n = 397$)	4.88	.93	−5.887	585	< .001	−.519
	HyFlex ($n = 190$)	5.38	.99				

*Welch's t-test was used due to unequal variances

Research question 2

While the results of research question 1 revealed differences in basic psychological needs (BPN) subscales such that the Interactive Synchronous HyFlex modality scores were higher than the traditional course delivery mode, research question 2 aimed to define which subscales of BPN, demographic variables, and semester were significant predictors of students' academic achievement. The regression analysis allowed us to model the relative magnitude of the predictors in concert with each other. We implemented a multilinear regression analysis to determine the relationship between the independent variables (autonomy satisfaction, competence satisfaction, relatedness to instructor, relatedness to peer, gender, ethnicity, residency, class rank, and semester) and the final course grades of students in HyFlex and face-to-face course delivery modes. While running the regression analysis, we encountered heteroscedasticity, and therefore, we used the Robust Standard Error technique for both regression analyses to obtain unbiased standard errors and accurate estimates. As predictor variables, demographic information and semester served as control variables in the regression analysis to examine their effects on the outcome variable. The first category of demographic variable was gender. It was coded as a binary variable: 'female' and 'male'. The second class rank category was categorized into three levels: "0–29 credit hours," "30–59 credit hours," and "60 + credit hours." Lastly, ethnicity was categorized into three levels: "underrepresented," "overrepresented," and "international". We excluded the "unknown" group from the analysis due to its ambiguous nature and lack

of meaningful interpretation as a predictor of academic success based on ethnicity. Each of the four semesters (Fall of 2019/2022 and Spring of 2019/2023) was represented with separate dummy variables, allowing us to capture variations in final course grades across semesters.

Separate regression analyses were run for Interactive Synchronous HyFlex and face-to-face modes to examine the unique relationships between the independent variable (IV) and dependent variable (DV) in both modes of instruction separately. This approach captured more nuanced insights in both modes, revealing their distinct characteristics of teaching and learning through a separate set of coefficients for all IVs in the two modes. Additionally, this method helped us avoid assuming that the relationship between IV and DV were the same for both instructional modes.

In regression analysis for both delivery modes, we computed final course grades based on mean scores of BPN (autonomy satisfaction, competence satisfaction, relatedness to peer, relatedness to instructor) and dummy variables for gender (female, male), class rank (0–29 credit hours, 30–59 credit hours, 60 + credit hours), ethnicity (Overrepresented, Underrepresented, and International), residency (Domestic and Foreign), and semester (Fall of 2019/2022 and Spring of 2019/2023). In demographic information, Purdue University categorized students as international who indicated their residency as foreign. This classification led to a multicollinearity issue within the dataset. The level of correlation between "International" and "Foreign" subcategories exceeded the threshold of 0.75, indicating a strong correlation (Mason & Perreault, 1991). Consequently, we excluded the "International" category from the analysis to ensure the robustness of the results.

The final regression model specification for both delivery modes is shown in Fig. 1 where *i* represents each student and the *Y* denotes the final course grade, which is the DV of this model. β represents the coefficient of each variable. "Male" from gender, "Overrepresented" from ethnicity, "First-year" from class rank, "Domestic" from residency, and "Fall" semester were used as reference groups in regression analysis.

Traditional face-to-face course delivery

The results of multiple regression are presented in Table 5. The results revealed that the final course grade can be significantly predicted in traditional course delivery settings, with the listed predictor variables, $F(10, 759) = 6.039$, $p = < 0.001$, with $R^2 = 0.061$, suggesting that the listed factors predict 6.1% of the variation. However, among BPN variables, only competence satisfaction ($B = 1.341$, $\beta = 0.183$, $p < 0.001$) and relatedness to peers ($B = 1.099$, $\beta = 0.127$, $p = 0.002$) were found to have a significant positive impact on students' final grades, while neither autonomy satisfaction ($B = -0.310$, $\beta = -0.049$, $p = 0.275$) nor relatedness to instructors ($B = -0.360$, $\beta = -0.048$, $p = 0.239$) significantly contributed to the predictions.

A statistically positive association was indicated while comparing the reference group (male) to female, indicating that females had significantly higher end-of-course grades

$$\mathbf{Y_i} = \beta_0 + \beta_1 Autonomy\ Satisfaction_i + \beta_2 Competence\ Satisfaction_i + \beta_3 Relatedness\ to\ Instructor_i + \beta_4 Relatedness\ to\ Peer_i + \beta_5 Female_i + \beta_6 Underrepresented_i + \beta_7 30 - 59\ credit\ hours_i + \beta_8 60 + credit\ hours_i + \beta_9 Foreign_i + \beta_{10} Spring_i + \varepsilon_i$$

Fig. 1 Regression model for predicting student academic performance

Table 5 Regression coefficient of traditional face-to-face course delivery

Parameter	B	Robust SE*	β	t	p	95% Confidence Interval
Intercept	82.073	2.079		39.485	< .001	77.993, 86.154
Autonomy satisfaction	− 0.310	0.284	− 0.049	− 1.092	0.275	− 0.868, 0.248
Competence satisfaction	1.341	0.398	0.183	3.368	< .001	0.559, 2.122
Relatedness to instructor	− 0.360	0.306	− 0.048	− 1.178	0.239	− 0.961, 0.24
Relatedness to peer	1.099	0.362	0.127	3.040	0.002	0.39, 1.809
Female	2.600	0.631	0.142	4.120	< .001	1.361, 3.838
Underrepresented	− 1.132	0.985	− 0.045	− 1.149	0.251	− 3.065, 0.802
30 − 59 credit hours	− 0.373	0.698	− 0.021	− 0.534	0.593	− 1.744, 0.998
60 + credit hours	− 0.432	0.789	− 0.023	− 0.547	0.585	− 1.981, 1.118
Foreign	1.001	0.862	0.040	1.162	0.246	− 0.691, 2.693
Spring 2019	− 1.445	0.623	− 0.089	− 2.317	0.021	− 2.669, − 0.221

*Robust standard errors were calculated using HC3 method

B = 2.600, β = 0.142, $p < 0.001$. Also, using the Fall of 2019 as a reference, students in the Spring of 2019 received significantly lower grades, B = -1.445, β = -0.089, $p = 0.021$. The results indicate that the other demographic variables (ethnicity, class rank, and residency) do not significantly predict the final course grades. Compared to overrepresented students, being an underrepresented student in the group was associated with a slight decrease in a final course grade. However, the impact was not statistically significant B = -1.132, β = -0.045, $p = 0.251$. In class rank, compared to the students in 0–29 credit hours group, students in 30–59 credit hours (B = -0.373, β = -0.021, $p = 0.593$) and 60 + credit hours (B = -0.432, β = -0.023, $p = 0.585$) group received slightly (but not significantly) lower final course grades.

HyFlex course delivery

The results revealed that the final course grade can also be significantly predicted in HyFlex course delivery settings, with listed predictor variables, $F(10, 422) = 5.232$, $p < 0.001$, with $R^2 = 0.089$, suggesting that the variables included predict a 8.9% variation. Regarding the BPN variables, only relatedness to instructor (B = 0.779, β = 0.139, $p = 0.035$) was a significant predictor, while neither autonomy satisfaction (B = -0.004, β = -0.001, $p = 0.992$), competence satisfaction (B = 0.781, β = 0.125, $p = 0.101$) or relatedness to peer (B = -0.616, β = -0.089, $p = 0.099$) significantly contributed to the predictions.

Among demographic variables, a statistically positive association was indicated in gender and class rank. The result showed that female students received statistically higher final course grades than males (B = 3.207, β = 0.198, $p < 0.001$). Compared to the students in the 0–29 credit hours group, the 30–59 credit hours group was associated with a statistically significant increase in a final course grade (B = 1.603, β = 0.106, $p = 0.033$). Students taking 60 + credit hours also showed an increase in final course grades compared to students in 0–29 credit hours group, but it is not statistically significant, B = 1.653, β = 0.088, $p = 0.075$. Although students received lower grades in Spring of 2023 compared to Fall of 2022 (reference group) the result was not statistically significant, B = -0.526, β = -0.036, $p = 0.479$. The results are described in Table 6.

Table 6 Regression Coefficient of HyFlex course delivery

Parameter	B	Robust SE*	β	t	p	95% Confidence Interval
Intercept	88.512	2.021		43.786	< .001	84.538, 92.485
Autonomy satisfaction	− 0.004	0.389	− 0.001	− 0.010	0.992	− 0.769, 0.762
Competence satisfaction	0.781	0.475	0.125	1.645	0.101	− 0.152, 1.715
Relatedness to instructor	0.779	0.368	0.139	2.116	0.035	0.055, 1.502
Relatedness to peer	− 0.616	0.372	− 0.089	− 1.655	0.099	− 1.348, 0.116
Female	3.207	0.679	0.198	4.722	< .001	1.872, 4.542
Underrepresented	− 0.601	0.981	− 0.029	− 0.613	0.54	− 2.53, 1.327
30 − 59 credit hours	1.603	0.751	0.106	2.135	0.033	0.127, 3.079
60 + credit hours	1.653	0.925	0.088	1.787	0.075	− 0.165, 3.47
Foreign	− 2.173	1.384	− 0.099	− 1.570	0.117	− 4.894, 0.547
Spring 2022	− 0.526	0.742	− 0.036	− 0.708	0.479	− 1.984, 0.933

*Robust standard errors were calculated using HC3 method

Discussion

Guided by the first research question, we examined the impact of Interactive Synchronous HyFlex on basic psychological needs compared to traditional face-to-face instruction using t-tests. The second research question prompted us to use the Robust Standard Error technique for multiple regression analyses to investigate relationships between instructional delivery modes and students' academic performance, including final course grades, demographic information, and the semester term. The results suggested that the Interactive Synchronous HyFlex course design meets students' basic psychological needs significantly better post-pandemic than the traditional face-to-face course delivery mode pre-pandemic. In our version of HyFlex, students consistently reported significantly higher satisfaction scores in autonomy, competence, and relatedness to peers and instructors across all four semesters, except for the Fall of 2019/2022, where the difference was only slightly higher. The BPN scores ranged from 4.6 to 5.6 in our HyFlex model and from 4.2 to 5.4 in the traditional course delivery on a scale of 1 to 7. Competence satisfaction, relatedness to peer, gender, and semester term are the most predictive factors of students' academic performance in traditional face-to-face teaching, while relatedness to instructor, gender, and class rank are the most predictive factors in our HyFlex teaching model. The summary of predictor variables is described in Table 7.

Several studies highlighted the mediating role of autonomy in increasing students' learning (Cheon et al., 2020; Furtak & Kunter, 2012; Gao et al., 2023; Holzer et al., 2021). We celebrate that our study found that students enrolled in Interactive Synchronous HyFlex mode reported significantly higher autonomy satisfaction scores in both the spring and fall semesters than in the traditional mode. The mean score of autonomy satisfaction was 4.9 in Fall 2022 and 4.6 in Spring 2023 in our version of HyFlex, which is close to "somewhat agree" in the ranking system to statements such as "I feel that my decisions reflect what I really want in this course" and "I feel a sense of choice and freedom in the things I undertake in this course." In the traditional version of the same course, the mean autonomy satisfaction score was 4.2 in Spring 2019 and 4.5 in Fall 2019, close to "Neither Agree nor Disagree." These results suggest that Interactive Synchronous HyFlex gave students autonomy to control their participation in the class based on their needs; even if students usually

Table 7 Comparison of Significance of Predictors on Final Course Grades in Traditional and HyFlex course delivery

Predictors	Traditional face-to-face only	HyFlex	Difference in predictors between face-to-face and HyFlex
Autonomy satisfaction			
Competence satisfaction	Significant (Positive)		Different
Relatedness to instructor		Significant (Positive)	Different
Relatedness to peer	Significant (Positive)		Different
Gender (Male vs Female)	Significant (Female > Male)	Significant (Female > Male)	
Ethnicity (Underrepresented vs Overrepresented)			
Credit hour (0–29 vs. 30–59)		Significant (0–29 < 30–59)	Different
Credit hour (0–29 vs 60 +)			
Nationality (Domestic vs Foreign)			
Term	Significant (Fall > Spring)		Different

Significance at the p = .05 level

attend face-to-face, they do not feel forced. Our results are consistent with literature, suggesting that HyFlex course delivery format had a positive impact on autonomy (Holzer et al., 2021) and contrasts with literature reporting a lower level of autonomy satisfaction compared to other psychological needs and non-significantly different level of autonomy satisfaction for HyFlex compared to the traditional face-to-face only format (Bozan et al., 2023; Mentzer et al., 2023a, 2023b).

Use of communication technology in our HyFlex learning experience potentially created additional opportunities that led to higher autonomy satisfaction. As long as students had a device to access the internet, they could quickly and easily join the class session. Additionally, the availability of classroom recordings allowed students the flexibility to revisit course content at their own pace and convenience, enabling them to engage more deeply with the material and increasing the effectiveness of HyFlex instruction (Kohnke & Moorhouse, 2021). Having the opportunity to review instructor facilitation and student discussions at students' convenience gives learners the autonomy to choose when and how they engage with course content, enhancing their perception of control over their learning process, which is essential to students' future success (Henri et al., 2018) and is aligned with the idea that technology can be a valuable tool to empower students in their learning journey when strategically integrated into instruction.

Competence in education was highlighted as a dominant need among other basic psychological needs (Ryan & Deci, 2017; Yu & Levesque-Bristol, 2020). Our findings supported this notion, as the mean of competence satisfaction scores were almost a full point higher than autonomy satisfaction for both educational models. In Interactive Synchronous HyFlex mode, competence satisfaction was significantly higher for spring semester than traditional face-to-face only instruction. In HyFlex, the mean reported score was 5.5 for

both semesters, which is somewhere between "somewhat agree" (5) and "agree" (6) compared to traditional face-to-face course delivery, which was 5.2 in Spring 2019 and 5.4 in Fall 2019, and is slightly closer to "somewhat agree" to a statement such as "I feel capable at what I do in this course." The score differences between the two delivery modes were relatively small, indicating that our version of HyFlex had a positive but limited impact on students' perceived competence in their coursework. Access to recorded videos with transcription at any time and digital class materials that allowed students to learn class lessons before coming to the class help them repeat and master the skills to finish their coursework (Zainuddin, 2018; Zainuddin & Perera, 2017). At the same time, having been immersed in intense technology usage during the pandemic, students most likely acquired valuable skills and strategies that empowered them to leverage these technological resources to support their academic pursuits effectively.

Relatedness showed significant improvement in the Interactive Synchronous HyFlex model with a mean score of 5.6 in Fall 2022 and 5.2 in Spring 2023 for relatedness to the instructor and 5.5 in Fall 2022 and 5.4 in Spring 2023 for relatedness to peer. These ranges situate the results within the zone of "somewhat agree" (5) and "agree" (6) to a statement like "The instructor(s) in this course care(s) about me" and "I really like the other students in this course." In the traditional face-to-face mode, while the mean score was 4.9 in Spring 2019 and 5.2 in Fall 2019 for relatedness to instructor, for peer relationship it was the same, 4.9, in both semesters. These results suggest that students felt more highly connected with their instructor and peers in HyFlex than in traditional course delivery mode. The enhanced relatedness to peers and instructors in HyFlex may have been facilitated by utilizing immediate live chat features that allowed remote and in-person students to engage in real-time discussion in the main chat and through backchannel interactions. We hypothesize that the use of video cameras and microphones further contributed to the sense of relatedness by enabling students to see and hear one another, when well-managed, bridging the physical and virtual divide. Further, students had multiple options to connect with instructors, whether it is via email, synchronous or asynchronous chat, voice call or video call with screen sharing on MS Teams, or during virtual office hours scheduled using software such as Bookings or Calendly. These findings are meaningful as a significant body of literature emphasizes the positive impact of relatedness to peer and instructor on students' development and satisfaction (Beachboard et al., 2011; Kuh & Hu, 2001; Shen et al., 2012).

The analysis driven by the second research question shed light on patterns and distinctions in the predictors of student academic performance across BPN and students' demographic backgrounds. Although our first research question discovered that the mean autonomy satisfaction scores were significantly higher in the HyFlex modality, these scores were not a significant predictor of students' final course grades in either educational model. This result indicates that students' sense of choice and freedom in their course participation and coursework did not strongly influence their academic performance within either course delivery model. Contrary to the existing literature, this implies that while providing students with autonomy in their learning decisions in both Interactive Synchronous HyFlex and traditional face-to-face instruction may have other benefits, it did not provide measurable impact on academic performance. This result was surprising as studies show that in HyFlex, having options in attendance modalities was highly appreciated by students and increased their engagement (Bockorny et al., 2023; Boylan et al., 2022). The lack of significant impact of autonomy on student performance may be because of the challenges and issues online learning environment brings to learning (Kebritchi et al., 2017; Shea & Bidjerano, 2010), such as self-regulation of your time to learn, work on assignments, and meet course deadlines.

Unlike autonomy satisfaction, the relationship between students' perceived competence satisfaction and final grades varied based on the instructional delivery mode. Even though the reported competence satisfaction score mean was slightly higher in HyFlex compared to traditional instruction, it was a significant predictor only for traditional face-to-face course delivery mode. Every one-point increase in a student's competence satisfaction score corresponds to an expected increase of 1.34 percentage points in their final course grade in traditional teaching. These findings align with the studies that suggest improving competence is an effective way to increase students' learning and highlight competence as a significant predictor of basic psychological needs in traditional classrooms (Wang et al., 2022). Explaining the absence of competence satisfaction as a significant predictor in HyFlex is challenging due to the need for more literature addressing the anticipated basic psychological needs connected to students' academic performance.

Relatedness was a significant predictor in both educational modes, but not in the same ways. Specifically, the relatedness to instructor was only significant as a predictor for Interactive Synchronous HyFlex, but not in the traditional classroom. For every one-point increase in a student's relatedness to instructor BPN score, a student's final course grade is expected to increase by 0.78 percentage. In our version of HyFlex, intensive communication and establishing robust connections between students and instructors are critical. In HyFlex, instructors must constantly work hard to balance connections with remote and in-class students, and the instructional design opens up different avenues for students to connect with their instructors. In addition to real-time verbal communication in the class and engagement during live video broadcasts, technology allows students to have brief chat exchanges with instructors via Microsoft Teams during out-of-class times, communicate via email, and request a virtual meeting using a designated scheduling weblink. This result is consistent with the literature exemplified by Athens (2023), where 72% of student participants indicated the crucial role of their instructors in influencing their academic performance versus only 36% of students who expressed satisfaction with the level of connections to their peers in HyFlex.

Relatedness to peers emerged as a significant predictor of students' course grades only in the traditional face-to-face teaching, even though the score means in HyFlex exceeded that in traditional teaching. The results show that for every one-point increase in a student's relatedness to peer score in traditional teaching, their final course grade is expected to increase by 1.1 percentage. This finding may indicate the critical reliance placed on peer interactions in traditional courses, where students often turn to their classmates for support in catching up with missed class activities or seeking clarification when they miss instructional content provided by the instructor.

Demographic factors were important for us to investigate as they are vital for equitable engagement to all student groups in our design course. When most students belong to a particular majority demographic, analyzing mean scores and predictors can disproportionately favor that group. Therefore, we introduced predictor variables related to demographics, enabling a more focused examination of equity across diverse student populations in the field of STEM. Significant differences were noted in gender, class rank and term among traditional and HyFlex modalities. Interestingly, a student's ethnicity (binarily categorized as over- or underrepresented) had no significant relationship to academic performance and neither did a student's nationality (domestic or foreign).

In our study, female students demonstrated significantly better academic performance than male students in both course delivery modes. In the traditional mode, female students achieved a 2.6 percentage point higher final course grade than their male counterparts, while in the HyFlex mode, this difference was more pronounced, with 3.21 percentage

points. Previous studies reached conflicted findings regarding gender-based disparities in academic performance. While previous research indicated that gender did not emerge as a statistically significant predictor of academic grades (Beyer, 2014) and had no gender disparities in grades (Seyranian et al., 2018), others revealed a tendency toward higher grades among male students (Hsieh & Yu, 2023) in the context of traditional STEM-related educational settings. However, future research studies are needed to analyze the disparate findings concerning gender-related course grades in HyFlex settings, particularly in STEM courses.

Class rank was also significant predictors of grades in HyFlex settings. Students in the 30–59 credit hours group did better than their peers in the 0–29 credit hours group only in the HyFlex modality. Students with 30–59 credits tended to receive 1.6 percentage points higher in final course grades than students in the 0–29 credit hours group. Transitioning from secondary to postsecondary education systems is complicated. The results of our study may be related to maturity and experience in navigating the additional participation choices where they can make better choices, and when they are remote, they can manage distraction-free environments more successfully. In light of these findings, further research is warranted to delve into the underlying reasons for these trends and to validate the observed results in HyFlex mode.

Significant variations were also observed between traditional face-to-face and HyFlex course delivery modes based on semester terms. In traditional teaching, students' academic performance was significantly better in the Fall of 2019 than in the Spring of 2019, with a notable 1.45 percentage points decrease in grades during the latter term. In contrast, the term was not a predictor of students' final course grades in HyFlex settings. These results suggest that seasonal changes may affect students' academic performance significantly in the traditional mode, which is consistent with the literature, except some reported that students performed better and had higher grade point averages (GPA) in the spring semester (Beşoluk & Önder, 2011; Graney et al., 2009). The reasons for our study's results remain unclear and are further complicated by the maturity of students such that with students typically starting in the fall term, the fall is their first semester and the spring is their second semester.

Limitations

This study used a large sample size of an introductory design course with a diverse group of undergraduate students representing multiple sections at Purdue University. The large sample size helped make our study potentially more representative of the undergraduate student population. This study measured the extent to which students reported their basic psychology needs had been met but did not examine changes in those needs pre or post pandemic. Recently published data from the American Enterprise Institute (Malkus, 2024) suggest that needs may have changed such that currently students may have additional need to be remote, potentially further elevating the value of HyFlex approaches.

We note this study may have a limitation related to self-reported surveys as this data type is inherently subjective (Bowman, 2010). Students who were highly engaged in the course or motivated by the prospect of extra credit may have been more likely to respond to study questions, and the non-responders might have supported an alternative conclusion. Data from slightly more than half of the students (53%) were not available due to low participation in survey completion which may have led to a biased sample and limited

the generalizability of the findings. Furthermore, the data loss may have resulted in a lack of statistical power, which could have affected the ability to detect significant differences between groups. Thus, the survey results may reflect the perspectives and experiences of a limited subset of the student population and may not be generalizable to a broader group of students.

Implications for future research and practice

Given that Interactive Synchronous HyFlex results showed an increase in all BPN scores throughout the year (though relatedness to the instructor was the only significant predictor of academic success in HyFlex), future studies should investigate strategies for building and enhancing this instructor to student connection. Investigating how instructors can establish robust relationships with students in a HyFlex setting and whether this relationship is a correlation or a causative factor in improving student grades could provide valuable insights.

Additionally, the consistent finding that female students outperformed male students in both delivery modes in our STEM course warrants further investigation. Future studies could explore whether this gender-based difference is linked to varying satisfaction levels with specific BPNs, shedding light on the underlying factors contributing to this disparity.

While the previous studies reached different results regarding the impact of HyFlex on students' basic psychological needs, our findings provide a promising perspective on implementing Interactive Synchronous HyFlex. Differences in previous literature and our findings may be related to the non-standard nature of HyFlex such that there are many nuanced variations in how HyFlex is delivered or differences may be related to course context or other variables.

Institutions should strategically integrate appropriate communication technologies into instruction to empower students and give them greater autonomy over their learning experiences. Offering options for remote or in-person attendance, recording lectures, providing digital course materials, and offering virtual office hours and options for communication can enhance students' autonomy, which, as our study suggests, can positively impact their satisfaction and engagement.

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