e-ISSN: 3062-228X

International Journal of Education and Artificial Intelligence

IJEDAI

Year : 2025 Volume : 2 Issue : 1

https://www.ijedai.com

Journal Name (Dergi Adı): International Journal of Education and Artificial Intelligence
Abbreviation (Kısa Adı): Int. J. Educ. and A.I
Short initials: (Baş Harfler): IJEDAI
Owner (Sahibi): Nail İLHAN
e-ISSN: 3062-228X
Frequency (Yayın Sıklığı): 2 issues per year (Yılda iki sayı)
Publication Data (Yayın Tarihi): 30-07-2025
Language (Dil): English or Turkish
Web Cite: https://www.ijedai.com/ **E-mail:** ijedaieditor@gmail.com
Adresse (Adress) : İnönü Üniversitesi, Eğitim Fakültesi, 44280, Malatya / TÜRKİYE

About, Aims and Scope

International Journal of Education and Artificial Intelligence (IJEDAI) is a refereed journal published twice a year, in English and Turkish, containing national and international articles. It publishes original and review studies in the field of education and artificial intelligence. All the manuscripts submitted to the IJEDAI are reviewed in a double blind review process. The aim of IJEDAI is to convey the current developments in the fields of education and artificial intelligence in the world and to be beneficial to science and humanity by sharing original studies. Articles to be accepted for IJEDAI may be from education and artificial intelligence studies, as well as from scientific fields related to education and artificial intelligence in a multidisciplinary manner.

Articles published in the IJEDAI reflect only the views of the author(s). Responsibility for the published content and articles belongs to the author. Editor, editorial board and publisher; accepts no responsibility or liability for the content of the authors' articles and opinions. IJEDAI is an "open access" journal and adopted the “open access policy”. Authors have their copyrights under the "Creative Commons Attribution-NonCommercial 4.0 International Licence". Details of the publication policies are available on the journal's website.

APA style is used for journal writing rules and details are available on the journal website.

Hakkında, Amaç ve Kapsam

International Journal of Education and Artificial Intelligence (IJEDAI) yayın dili İngilizce ve Türkçe olan, ulusal ve uluslararası makaleler içerecek şekilde, yılda iki kez yayımlanan, hakemli bir dergidir. Eğitim veya eğitim ve yapay zekâ alanında orijinal ve derleme çalışmalarını yayınlamaktadır. IJEDAI, gönderilen makaleler için en az iki hakem tarafından değerlendirilen çift-kör hakem değerlendirme sürecini benimsemektedir. IJEDAI 'nin amacı dünyadaki eğitim ile ilgili çalışmalarda ve yapay zekânın eğitim alanındaki uygulamalarında kaydedilen güncel gelişmeleri aktarmak; özgün çalışmaların paylaşılmasını sağlayarak bilim ve insanlığa faydalı olmaktır. IJEDAI için kabul edilecek makaleler eğitim ve yapay zekâ çalışmalarının yanı sıra, multidisipliner olarak eğitim ve yapay zekâ ile ilgili çeşitli bilim alanlarından olabilir.

Dergide yayınlanan makaleler yalnızca yazar(lar)ın görüşlerini yansıtır. Yayınlanan makale ve içeriklerdesorumluluk yazara aittir. Editör, yayın kurulu ve yayıncı; yazarların makale ve içeriklerine yönelik sorumluluk ya da yükümlülük kabul etmemektedir. IJEDAI "açık erişim" dergisi olup, "açık erişim politikasını" benimsemiştir. IJEDAI, "Creative Commons Attribution-NonCommercial 4.0 International Licence" ile lisanslanmıştır. Yayın politikalarının detaylarına dergi web sayfasında yer verilmiştir.

Dergi yazım kuralları için APA stili kullanılmakta olup detaylar dergi web sayfasında bulunmaktadır.

Indexing:

OpenAIRE European Commission Funded Research (OpenAIRE)

CONTENTS (İÇİNDEKİLER)

International Journal of Education and Artificial Intelligence

Publishing Policy & Ethics

International Journal of Education and Artificial Intelligence (IJEDAI) is a peer-reviewed, electronic, and scientific journal which adheres to the following ethical principles and considerations in order to publish articles in the field of education and artificial intelligence. The aim of IJEDAI is to convey current developments in education and artificial intelligence in education in the world, and to benefit science and humanity by sharing original studies. Articles to be accepted for IJEDAI can be from various scientific fields related to education and artificial intelligence, as well as multidisciplinary studies.

Articles sent to IJEDAI for publication are reviewed through a double-blind process and published online. For the IJEDAI Journal, the ethical responsibilities, roles and duties for the journal editor, authors, reviewers and publisher are explained below.

The ethical duties and responsibilities in IJEDAI have been prepared by taking into account the ethical and publication policies of internationally journals and the guidelines published by the "Committe on Publication Ethics" - COPE as open access. In other matters not mentioned in IJEDAI, COPE's ethical principles are taken into account.

The editor-in-chief can take part in determining the of the editorial board/Editor and improving the quality of the journal. If the Editor-in-Chief sees necessary, he/she may assign an Editor for the article or may conduct the scientific assessment of the article himself/herself. Authors/Editors/Reviewers must be taken into consideration the ethical codes: Authorship, Plagiarism (including self-plagiarism), Data fabrication / data falsification, Duplicate submission, Corrections and retractions, Human and Animal Rights, Conflicts of interest / Competing interests, Intellectual property

Ethical Responsibilities of Author(s)

The authors should submit their original works to IJEDAI in the field of education and artificial intelligence. All of sources used in the articles must be cited in accordance with the latest published style of the American Psychological Association (APA). Authors must certify that their manuscripts are their original work. Authors are expected to adheres to International Standards for Authors developed by the Committee on Publication Ethic (https://publicationethics.org/files/International%20standards_authors_for%20website_11_Nov_2011.pdf)

'Copyright Transfer Form' must be filled out and upload by the corresponding author for articles submitted to the journal. Individuals who have not contributed to the study of a manuscripts must not be indicated as authors. Any studies published in any journal or as a book cannot be sent to IJEDAI. Authors cannot submit their study, which is currently under review in another journal, to IJEDAI at the same time. If there are any conflicting interests regarding the submitted article, they must be declared. It should be stated whether the submitted articles are derived from conferences/thesis/projects and similar research. Articles published in full text (proceeding paper) at conferences cannot be submitted for publication for IJEDAI. For studies requiring human participation, authors are required to obtain "Ethics Committee Approval" from the relevant institutions.

In giving ethics committee approvals, such as the Declaration of Helsinki (https://www.wma.net/policies-post/wma-declaration-of-helsinki-ethical-principles-for-medical-research-involving-human-subjects/#:~:text=The%20World%20Medical%20Association%20(WMA,identifiable%20human%20material%20and%20data). It is important to verify that recognized standards are valid. If it is necessary, raw data regarding their articles may be requested from the author(s) within the framework of the evaluation processes. Authors are obliged to keep their raw data for at least 5 years after their articles are published.

Ethical Responsibilities of Reviewers

IJEDAI has adopted a double-blind peer review process for submitted manuscripts, which are reviewed by at least two reviewers. After the reviewers review process, in case of uncertainty, the final decision is

Yayın Politikası & Etik

International Journal of Education and Artificial Intelligence (IJEDAI) eğitim ve yapay zekâ alanındaki bilimsel makaleleri yayımlamak amacıyla aşağıda belirtilen etik ilkeler ve kurallara bağlı olarak basılan hakemli bir dergidir. IJEDAI 'nin amacı dünyada eğitim alanında ve eğitimde yapay zekânın kullanımı ile ilgili kaydedilen güncel gelişmeleri aktarmak; özgün çalışmaların paylaşılmasını sağlayarak bilim ve insanlığa faydalı olmaktır. IJEDAI için kabul edilecek makaleler eğitim ve yapay zekâ çalışmalarının yanı sıra, multidisipliner olarak eğitim ve yapay zekâ ile ilgili çeşitli bilim alanlarından olabilir.

IJEDAI 'ne yayınlanmak için gönderilen makaleler çift-kör hakem süreciyle değerlendirilmekte ve dergi çevrimiçi olarak yayımlanmaktadır. IJEDAI Dergisi'ne yönelik dergi editörünün, yazarların, hakemlerin ve yayıncının etik sorumlulukları, rolleri ve görevleri aşağıda açıklanmıştır.

IJEDAI 'de yer alan etik görev ve sorumluluklar, uluslararası dergilerin etik ve yayım politikaları incelenerek ve açık erişim olarak "Committe on Publication Ethics" - COPE tarafından yayımlanan yönergeler dikkate alınarak hazırlanmıştır. IJEDAI'da belirtilmeyen diğer hususlar da COPE 'da belirtilmiş olan etik prensipleri dikkate alınır.

Baş Editör, editör kurulu üyelerinin belirlenmesinde ve dergi kalitesinin geliştirilmesinde her aşamada görev alabilir. Baş Editör gerekli gördüğü takdirde makaleye bir editör görevlendirebilir veya makalenin bilimsel değerlendirmesini kendisi yapabilir. Yazarlar/Editörler/Hakemler in dikkat edeceği etik kurallar; Yazarlık, İntihal, veri uydurma / veri tahrifatı, tekrarlı gönderim, düzeltmeler ve geri çekilme, insan ve hayvan hakları, çıkar çatışmaları / rekabet menfaatler, fikri mülkiyet

Yazarların etik sorumlulukları

Yazarların IJEDAI Dergisi'ne gönderdikleri makalelerin eğitim ve yapay zeka alanında özgün çalışmalar olması gerekmektedir. Makalelerde yararlanılan tüm kaynaklar American Psychological Association (APA)'nın yayınlanan son sitiline uygun bir şekilde gösterilmelidir. Yazarlar, yazılarının kendilerine ait olduğunu belgelendirmelidir. Yazarların Yayın Etiği Komitesi tarafından geliştirilen Yazarlar için Uluslararası Standartlara uymaları beklenmektedir https://publicationethics.org/files/International%20standards_authors_for%20website_11_Nov_2011.pdf)

Dergiye gönderilen makaleler için sorumlu yazar tarafından 'Telif Hakkı Devir Formu' doldurulmalı ve dergiye gönderilmelidir.

Bir makale çalışmasında katkısı bulunmayan kişiler yazar olarak belirtilmemelidir. Daha önce herhangi bir şekilde başka bir dergide veya kitap olarak yayımlanmış çalışmalar IJEDAI'ye gönderilemez. Yazarlar, başka bir dergide henüz değerlendirme aşamasında olan çalışmasını aynı anda IJEDAI 'ye gönderemez. Gönderilen makaleye yönelik çıkar çatışmaları durumları varsa belirtilmelidir. Gönderilen makalenin konferans/tez/proje araştırmalardan türetilme durumu belirtilmelidir. Konferanslarda tam metin olarak yayınlanan makaleler IJEDAI için yayına gönderilemez. Yazarlar etik kurul onayı gerektiren çalışmaları için ilgili kurumlardan "Etik Kurul Onayı" almaları gerekmektedir. Etik kurul onaylarının verilmesinde Helsinki Bildirgesi gibi (https://www.wma.net/policies-post/wma-declaration-of-helsinki-ethical-principles-for-medical-research-involving-human-subjects/#:~:text=The%20World%20Medical%20Association%20(WMA,identifiable%20human%20material%20and%20data) tanınmış standartların geçerli olduğu doğrulanması önemlidir. Gerekli durumlarda, yazar(lar)dan değerlendirme süreçleri çerçevesinde makalelerine ilişkin ham veri talep edilebilir. Yazarlar, makaleleri yayımlandıktan sonra ham verilerini en az 5 yıl süreyle saklamakla yükümlüdürler.

Hakemlerin Etik Sorumlulukları

IJEDAI gönderilen makaleler için en az iki hakem tarafından değerlendirilen çift-kör hakem değerlendirme süreci benimsenmiştir. Hakem değerlendirmelerinden sonra belirsizlik durumunda editörün

taken with the opinion of the editor or a third referee. The reviewers are required to notify the editor of their decision as to whether the manuscript they have reviewed is publishable or not and their reasons for so doing so.

The ethical responsibilities of Reviewers at IJEDAI are as follows:

Reviewers are expected to read publishing principles, aim and scope of the IJEDAI. Reviewers must review the manuscripts related to their field of expertise. Reviewers must review manuscripts which they do not have any conflict of interests. Manuscripts must be evaluated by reviewers within the framework of unbiased and objective manner. Reviewers should use constructive, polite, and scientific language in review reports and reviewing process. Reviewers should not make comments that may be disrespectful, insulting, offensive or slanderous. Reviewers should complete the manuscript review process within a specific time frame given to them.

Ethical Responsibilities of Editors

IJEAI editors and field editors must adhere to the ethical responsibilities based on guidelines for editors published by "Committee on Publication Ethics" (COPE). The editor manages all processes until the manuscripts sent to the journal are published. The general responsibility of editors is as follows; Ensuring the general development of the journal, managing processes to increase the quality of studies published in the journal, updating the ethical policies together with other members of the journal's editorial boards.

Editors must also adhere to the responsibilities listed below.

Relations with readers:

The editors should ensure that the non-peer-reviewed sections of the journal (letters, essays, etc.) are identified. The editors should make efforts to ensure that the articles published in accordance with the purpose and scope of the journal are align with the knowledge and skills of the readers. The editors should consider reader feedback regarding journal publishing, scope, and ethics.

Relations with the reviewers;

Editors must choose reviewers in related field of the study and update the pool of reviewers. Editors must provide necessary information for questions of reviewers about manuscript review process and remind reviewers about timing. Editors must ensure guidelines needed by reviewers during manuscript review process. Editors must be careful any conflict of interest between authors and reviewers. Editor should evaluate reviewers in terms of performance, timing, polite, and quality.

Relations with the authors;

Editors must provide the guidelines and a template needed by authors during the manuscript submission process. Editors must be careful about conflict of interest between authors and reviewers. Editors must to inform authors about publication, ethical policies, manuscript review process and timing. The editor must convey the information and reasons regarding the accepting or rejecting of the manuscript to the author within the specified time. If the authors decide to correct the article, the authors should be informed and given time to make the corrections. Editors must approve authors' requests to withdraw their studies under review process. Editors should evaluate authors' objections to reviewers decisions/reports and, if necessary, initiate a new review process.

Relations with editorial board members;

Editors must provide information and guidelines to the editorial board members about publishing and ethical policies of the journal. Editor should select and update the editorial board members who will contribute to the journal's development. Editors should take into account feedbacks and the opinions of the editorial board in improving the journal. The editor should review and improve the journal publishing and writing rules with the editorial board. The editor should be able to assign responsibilities to members of the editorial board in some tasks in the development of the journal.

veya üçüncü bir hakemin görüşü ile nihai karar alınır. Hakemler, değerlendirdikleri makalenin yayımlanabilir olup olmadığına ilişkin kararlarını ve buna yönelik gerekçelerini editöre bildirmeleri gerekmektedir.

IJEDAI 'de görev alan hakemlerinin etik sorumlulukları aşağıdaki gibidir:

Hakemlerden IJEDAI 'nin yayım ilkeleri, amaç ve kapsamını okumaları beklenmektedir. Hakemler uzmanlık alanı ile ilgili çalışmaları değerlendirmeyi kabul etmelidirler. Hakemler çıkar çatışması olmayan çalışmalara hakemlik yapmalıdır. Hakemler tarafından makaleler tarafsızlık ve gizlilik çerçevesinde değerlendirmeler yapılmalıdır. Hakemler değerlendirme raporlarında ve yazışmalarda yapıcı, nazik ve bilimsel bir dil kullanmalıdır. Hakemler, saygısızlık içerebilecek, hakaret, saldırganlık ve iftira olabilecek yorumlar yapmamalıdır. Hakemler makaleyi değerlendirme sürecini kendilerine verilen belirli bir zaman çerçevesinde tamamlamalıdır.

Editörün Etik Sorumlulukları

IJEAI editörü ve alan editörleri, "Yayın Etiği Komitesi" (COPE) nin editörler için yayınlamış olduğu kılavuzlarda yer alan etik sorumluluklara uyması gerekmektedir. Editör, dergiye gönderilen makalelerin yayınlanmasına kadar geçen bütün süreçleri yönetir. Editörlerin genel sorumluluğu şöyledir; derginin genel olarak gelişimini sağlama, dergide yayımlanan çalışmaların kalitesini arttırmaya yönelik süreçleri yönetme, derginin editör kurullarındaki diğer üyelerle birlikte etik politikalarında da güncelleme yapmadır.

Ayrıca editörler aşağıda belirtilen sorumlulukları da yerine getirmelidir.

Okuyucularla İlişkiler:

Editörler, dergide hakem değerlendirmesi gerekli olmayan bölümlerin düzenlenmesini (mektuplar, makaleler, konferans duyuruları vb.) sağlamalıdır. Editörler, derginin amaç ve kapsamına uygun olarak yayınlanan makalelerin okuyucuların bilgi ve becerilerine uygun olması için çaba göstermelidir. Editörler, okuyucunun dergi yayımlama, kapsam ve etik ile ilgili geri bildirimlerini dikkate almalıdır.

Hakemlerle İlişkiler;

Editörler, çalışmanın ilgili alanındaki hakemleri seçmeli ve hakem havuzunu güncellemelidir. Editörler, hakemlerin makale inceleme sürecine ilişkin sorularına gerekli bilgileri sağlamalı ve hakemlere zamanlama konusunda hatırlatmada bulunmalıdır. Editörler, makale inceleme sürecinde hakemlerin ihtiyaç duyduğu yönergeleri sağlamalıdır. Editörler, yazarlar ve hakemler arasındaki çıkar çatışmalarına karşı dikkatli olmalıdır. Editör, hakemleri performans, zamanlama, nezaket ve kalite açısından değerlendirmelidir.

Yazarlarla İlişkiler;

Editörler, makale gönderim sürecinde yazarların ihtiyaç duyduğu yönergeleri ve şablonu sağlamalıdır. Editörler, yazarlar ve hakemler arasındaki çıkar çatışmalarına karşı dikkatli olmalıdır. Editörler yazarları yayın, etik politikalar, makale inceleme süreci ve zamanlaması konusunda bilgilendirmelidir. Editör, yazının kabul veya reddedilmesine ilişkin bilgi ve gerekçeleri belirtilen süre içerisinde yazara iletmelidir. Yazarların makaleyi düzeltmeye karar vermesi durumunda yazarlara bilgi verilmeli ve düzeltmeleri yapmaları için süre tanınmalıdır. Editörler, yazarların inceleme sürecindeki çalışmalarını geri çekme isteklerini onaylamalıdır. Editörler, yazarların hakem kararlarına/raporlarına olan itirazlarını değerlendirmeli ve gerekiyorsa yeni bir inceleme süreci başlatmalıdır.

Editör Kurulu İle ilişkiler;

Editörler, yayın kurulu üyelerine derginin yayıncılığı ve etik politikaları hakkında bilgi ve yönergeler sağlamalıdır. Editör, derginin gelişimine katkıda bulunacak yayın kurulu üyelerini seçmeli ve güncellemelidir. Editörler dergiyi geliştirirken yayın kurulunun geri bildirimlerini ve görüşlerini dikkate almalıdır. Editör, editör kurulu ile dergi yayım ve yazım kurallarınını gözden geçirmeli ve

Journal Policy

Reviewing and Publishing Policy

Articles sent to IJEDAI for publication are reviewed through a double-blind process and published online. 'Copyright Transfer Form' must be filled out and upload by the corresponding author for articles submitted to the journal. Authors cannot submit their study, which is currently under review in another journal, to IJEDAI at the same time.

All of sources used in the articles must be cited in accordance with the latest published style of the American Psychological Association (APA). Any studies published in any journal or as a book cannot be sent to IJEDAI. It should be stated whether the submitted articles are derived from conferences/thesis/projects. Articles published in full text (proceeding paper) at conferences cannot be submitted for publication for IJEDAI. All of sources used in the articles must be cited in accordance with the latest published style of the American Psychological Association (APA). All responsibility for the published articles/writting belongs to the author(s). Author(s) have the responsibility of all contents in the manuscript/article/writing.

Peer Review Process Policy

For publication, all manuscripts submitted to the IJEDAI are pre-reviewed by the Editor or Editorial Board in terms of scope and writing rules. Editor may reject the submissions which do not comply with the principles of the IJEDAI. The pre-reviewing process is completed in 10 days. After the pre-reviewing, all manuscripts are sent to at least two independent reviewer for blind peer review. The reviewers are asked to judge the scientific, validity, significance, and originality of manuscripts. The reviewer' assessment period is 30 days, this period can be extended if necessary. If the reviewer' assessment period is not completed on time, the editor may send the article to a new reviewers.If different opinions are expressed from the reviewers, the editor may send the article to a third reviewer for assessment. If there are the revisions recommended by the Reviewer/Editor, the time required for the authors to make these is a maximum of 30 days. The publication process begins for articles accepted for publication by the Editor/Editorials board. The final revised of the articles in accordance with the IJEDAI writing format is performed by the author(s). After the proofreading process, volume, issue and page numbers is assigned and the manuscript appears in Online First section. Article withdrawal cannot be made for manuscript that have been peer-reviewed and accepted.

Generative Artificial Intelligence (AI) Policy

IJEDAI embraces the use of AI-powered technologies. However, generative AI and AI-powered technologies may only be used to improve the academic language of a study and correct typographical errors. The use of AI for purposes such as the Introduction, Literature Review, Methodology, Data Analysis, Results, Inferences Based on These Results, and Writing the Discussion is strictly prohibited. Authors must clearly state in the manuscript any purposes for which AI is used beyond these.

Even if AI technologies are used for purposes such as improving the language of the study, they must be used under human supervision, and the final version must be reviewed and verified by the author(s). Because AI can make mistakes, responsibility rests entirely with the author(s). Author(s) must specify which AI tools were used and for what purpose at the end of their submitted work. This statement will be included in the published manuscript. It is important for authors to adhere to AI usage policies.

Plagiarism Policy of IJADAI

The publishing rights of the published work belong to the journal. The IJEDAI is strictly against any plagiarism in any form. Authors must submit only entirely original manuscripts and appropriately cite or quote the work and/or words of others. Guidelines published by the “Committe on Publication Ethics” - COPE are taken into account. The COPE guidelines on plagiarism are followed. APA style are used in quoting and citing sources. Manuscripts submitted to the IJEDAI is checked for originality using anti-plagiarism software like Turnitin/ iThenticate. The similarity rate of the accepted manuscript must be not exceeded the rate of 20%. American Psychological Association. (2020). Publication manual of the American Psychological

Dergi Politikaları

Hakemlik ve Yayın Süreci Politikaları

IJEDAI ’ne yayınlanmak için gönderilen makaleler çift-körl hakem süreciyle değerlendirilmekte ve çevrimiçi olarak yayımlanmaktadır. Dergiye gönderilen makaleler için sorumlu yazar tarafından 'Telif Hakkı Devir Formu' doldurulmalı ve dergiye gönderilmelidir. Yazarlar, başka bir dergide henüz değerlendirme aşamasında olan çalışmasını aynı anda IJEDAI ’ye gönderemez. Gönderilen makalenin konferans/tez/proje araştırmalardan türetilme durumu belirtilmelidir. Konferanslarda tam metin olarak yayınlanan makaleler IJEDAI için yayına gönderilemez. Makalelerde yararlanılan tüm kaynaklar American Psychological Association (APA)’nın yayınlanan son sitiline uygun bir şekilde gösterilmelidir. Yayımlanan yazıların/makalelerin her türlü sorumluluğu yazar(lar)a aittir.

Hakem Değerlendirme Süreci Politikaları

Yayınlanmak üzere IJEDAI 'ye gönderilen tüm yazılar, Editör veya Yayın Kurulu tarafından kapsam ve yazım kuralları açısından ön incelemeye tabi tutulur. Editör, IJEDAI ilkelerine uymayan yazıları reddedebilir. Ön inceleme süreci 10 gün içerisinde tamamlanır. Ön incelemeden sonra tüm yazılar kör hakemlik için en az iki bağımsız hakeme gönderilir. Hakemlerden yazıların bilimselliğini, geçerliliğini, önemini ve orijinalliğini değerlendirmeleri istenir. Hakem değerlendirme süresi 30 gündür, gerek görülmesi halinde bu süre uzatılabilir. Hakem değerlendirme süresinin zamanında tamamlanmaması durumunda editör, makaleyi yeni hakemlere gönderebilir. Hakemlerden farklı görüş bildirilmesi halinde editör, makaleyi değerlendirilmek üzere üçüncü hakeme gönderebilir. Hakem/Editör tarafından önerilen düzeltmeler varsa yazarların bunları yapması için gereken süre en fazla 30 gündür. Editör/Editör Kurulu tarafından yayına kabul edilen makaleler için yayın süreci başlar. Makalelerin IJEDAI yazım formatına göre son revizyonu yazar(lar) tarafından gerçekleştirilir. Düzeltme işleminden sonra cilt, sayı ve sayfa numaraları atanır ve makale Önce Online bölümünde görünür. Hakem değerlendirmesi yapılmış ve kabul edilmiş makaleler için makale geri çekme işlemi yapılamaz.

Üretken Yapay Zeka (AI) Politikası

IJEDAI AI destekli teknolojilerin kullanımını benimsiyor. Ancak, üretken AI ve AI destekli teknolojiler yalnızca çalışmanın akademik yazım dilini geliştirmek ve yazım hatalarını düzeltmek için kullanılabilir. AI’nın Giriş, literatür, metodoloji, verilerin analiz edilmesi, Sonuçlar, sonuçlarına dayalı çıkarımlarda bulunulması ve tartışma bölümünün yazılması gibi amaçlar için kullanımı kesinlikle yasaktır. Bunların dışındaki AI’nin hangi amaçlarla kullanıldığı durumları yazarlar tarafından makalede açıkca belirtilmelidir.

AI teknolojileri çalışmanın dilini geliştirmek gibi amaçlar için kullanılsa bile, insan gözetimi altında kullanılmalı ve son sürüm yazar(lar) tarafından incelenmeli ve doğrulanmalıdır. AI'nın hata yapabilmesi durumu söz konusu olduğundan sorumluluk tamamen yazar(lar)a aittir. Yazar(lar) gönderilen çalışmalarının sonunda hangi AI araçlarınını hangi amaçla kullanıldığını belirtmelidir. Bu ifade yayınlanan makalede yer alacaktır. Yazarların AI kullanım politikalarına uymaları önemlidir.

IJEDAI'in İntihal Politikası

Yayınlanan eserin yayın hakları dergiye aittir. IJEDAI, her türlü intihale kesinlikle karşıdır. Yazarlar yalnızca tamamen orijinal yazılar sunmalı ve başkalarının çalışmalarından ve/veya sözlerinden uygun şekilde alıntı yapmalı veya alıntı yapmalıdır. “Yayın Etiği Komitesi” - COPE tarafından yayınlanan kılavuzlar dikkate alınır. İntihalle ilgili COPE yönergelerine uyulur. Kaynakların alıntılanmasında ve alıntılanmasında APA stili kullanılır. IJEDAI 'ye gönderilen yazılar, Turnitin/iThenticate gibi intihal önleme yazılımı kullanılarak orijinallik açısından kontrol edilir. Kabul edilen yazının intihal açısından benzerlik oranının %20 oranını geçmemesi gerekmektedir.

American Psychological Association. (2020). Publication manual of the American Psychological Association(7th ed.). https://apastyle.apa.org/ , https://publicationethics.org/

Association(7th ed.). https://apastyle.apa.org , https://publicationethics.org

Publication Fee

International Journal of Education and Artificial Intelligence (IJEDAI) is a peer-reviewed scholarly online free journal. There is no publication fee.

Licencing and Copyright Policy

Any studies published in any journal or as a book cannot be sent to IJEDAI. Authors have their copyrights under the Creative Commons CC BY-NC. 'Copyright Transfer Form' must be filled out and upload by the corresponding author for articles submitted to the journal.

Open Access Policy

All papers are licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License

IJEDAI is an "open access" journal and adopted the “open access policy”. The content of the International Journal of Education and Artificial Intelligence is licensed under Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License

Ücret Politikaları

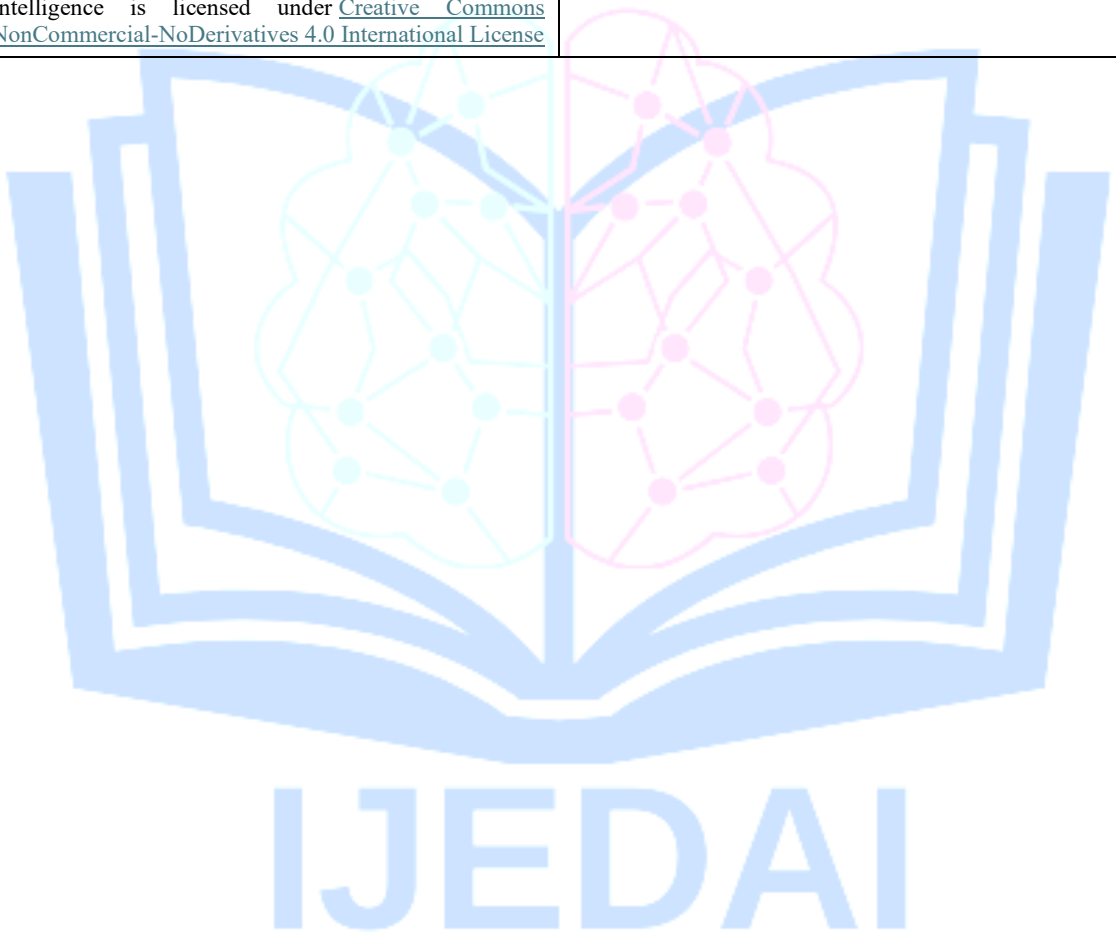
International Journal of Education and Artificial Intelligence (IJEDAI), hakemli, bilimsel, çevrimiçi ücretsiz bir dergidir. Yayın ücreti yoktur.

Telif Devir Hakkı

Daha önce herhangi bir şekilde dergide veya kitap olarak yayımlanmış çalışmalar IJEDAI’ye gönderilemez. Dergiye gönderilen makaleler için sorumlu yazar tarafından 'Telif Hakkı Devir Formu' doldurulmalı ve dergiye gönderilmelidir.

Açık Erişim Politikası

IJEDAI "açık erişim" dergisi olup, "açık erişim politikasını" benimsemiştir. IJEDAI, "Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License" ile lisanslanmıştır.



Editorial

International Journal of Educational and Artificial Intelligence
Volume 1, Issue 1, Page 1-2

ISSN: 3062-228X
http://www.ijedai.com/

Editorial for Volume 2 Issue 1 of IJEDAI

Nail İlhan [1*]

[1] Department of Mathematics and Science Education, Faculty of Education, İnönü University, Türkiye

INTRODUCTION

International Journal of Educational and Artificial Intelligence (IJEDAI) continues to contribute to researchers and readers with the articles published in this new issue. Studies conducted by researchers from many different universities have been evaluated by different referees. The evaluations and suggestions of the referees have made very valuable contributions in terms of making the articles more qualified. Thanks to the researchers and referees who worked hard for the articles published in the journal.

Articles published in this issue; "Maximizing the impact of artificial intelligence and generative AI on STEAM education: A comprehensive review" by Er et al. (2025), "Bibliometric analysis of formative assessment research in science education" by Sadi-Yılmaz (2025), and "Academics' views on problems and solutions in biology education in 21st century Turkey" by Kuru-Kaçmazoğlu & Özmen (2025). A word cloud has been created from the key concepts mentioned in this issue of IJEDAI for readers.

Figure 1. Word cloud for IJEDAI keywords

REFERENCES

Er, Z., İlhan, A. G., & Bülbül, M. Ş. (2025). Maximizing the impact of artificial intelligence and generative AI on STEAM education: A comprehensive review. *International Journal of Educational and Artificial Intelligence, 2*(1), 3-16. https://doi.org/10.5281/zenodo.16606275

Kuru Kaçmazoğlu, E., & Özmen, N. (2025). Academics' views on problems and solution in biology education in 21st century Türkiye. *International Journal of Educational and Artificial Intelligence, 2*(1), 41-55. https://doi.org/10.5281/zenodo.16620381

Sadi Yılmaz, S. (2025). Bibliometric analysis of formative assessment research in science education. *International Journal of Educational and Artificial Intelligence, 2*(1), 17-40. https://doi.org/10.5281/zenodo.16615094

Research Article https://doi.org/10.5281/zenodo.16606275

International Journal of Educational and Artificial Intelligence

Year 2025, Volume 2, Issue 1, Page 3 - 16

ISSN: 3062-228X
http://www.ijedai.com/

Maximizing the impact of artificial intelligence and generative AI on STEAM education: A comprehensive review

Zübeyde Er [1*], Ayşe Gül İlhan [2], Mustafa Şahin Bülbül [3]

[1] Çukurova Science and Art Center, Adana, Türkiye
[2] Technology Laboratory (Teknolab) Social Activity and Development Center, Kayseri, Türkiye
[3] Dede Korkut Faculty of Education, Kafkas University, Kars, Türkiye

Article Info

Submitted: 25.01.2025
Accepted: 18.04.2025
Published Online: 30.07.2025

Keywords
STEAM Education
Artificial Intelligence
Generative AI
Creative Thinking
Problem-Solving
Interdisciplinary Learning
Personalized Learning
Adaptive Learning
Ethical AI Integration

*Corresponding Author:

Zübeyde Er
E-mail: zbeyde-er@windowslive.com

Abstract

This paper extends the discussion on the significance of STEAM (Science, Technology, Engineering, Arts, and Mathematics) education by examining the rapidly emerging roles of Artificial Intelligence (AI) and Generative AI (GAI) in fostering critical thinking, problem-solving, and creativity. By integrating these advanced technologies into STEAM curricula, educators can provide more personalized, interdisciplinary, and engaging learning experiences that cater to varied student needs. Throughout the paper, AI and GAI platforms are categorized into subgroups namely Adaptive Learning & Personalized Education, Programming & Data Analysis, Generative & Creative AI, Interactive & Immersive Learning, and Visual Design & Communication to illustrate diverse integration pathways. Ethical considerations, pedagogical strategies, and continuous teacher development are presented as key to responsible adoption. This review study includes the analysis of various peer-reviewed studies selected based on specific inclusion and exclusion criteria. Findings underscore the transformative potential of AI and GAI not only in enhancing student engagement and conceptual mastery, but also in promoting collaborative innovation across all STEAM disciplines. The study concludes with actionable recommendations for educators, policymakers, and researchers to embed AI and GAI tools effectively while ensuring equitable access, maintaining ethical standards, and emphasizing long-term professional growth.

To cite this article:

Er, Z., İlhan, A. G., & Bülbül, M. Ş. (2025). Maximizing the impact of artificial intelligence and generative AI on STEAM education: A comprehensive review. *International Journal of Educational and Artificial Intelligence, 2*(1), 3-16. https://doi.org/10.5281/zenodo.16606275

1. INTRODUCTION

Education plays a pivotal role in equipping individuals with critical thinking, problem-solving, and creativity skills vital for personal and societal development. In this context, STEAM (Science, Technology, Engineering, Arts, and Mathematics) education transcends traditional subject boundaries by promoting an interdisciplinary mindset (Tsupros et al., 2009). Scholars have pointed out that STEAM education not only delivers academic content but also nurtures the competencies required in our rapidly evolving world, encouraging students to generate creative solutions to complex problems (Tüzün & Tüysüz, 2018; Erol, 2023).

As rapid advancements in AI continue to shape multiple sectors, education has increasingly embraced these technologies to enhance student engagement and tailor learning experiences (Russell & Norvig, 2021; Ece, 2024). Among the noteworthy AI subfields is Generative AI (GAI), which has the capacity to create new content such as text, images, and music by analyzing patterns within given datasets (Liu, 2023; Vafadar & Amani, 2024). This study aims to examine the role of Artificial Intelligence (AI) and Generative AI (GAI) in STEAM education, exploring how these technologies support students' critical thinking, problem-solving, and creativity skills. Serving as a guide for educators, policymakers, and researchers, this study systematically categorizes AI and GAI tools to provide a structured framework for their effective integration into STEAM curricula. Furthermore, it addresses key considerations such as ethical concerns, teacher training, and student-centered approaches, offering recommendations for the sustainable and effective implementation of AI-enhanced STEAM education.

1.2. The Importance of STEAM Education

STEAM education supports students' acquisition of 21st-century skills, which include creativity, critical thinking, problem-solving, collaboration, ethical behavior, aesthetic awareness, initiative-taking, communication, data literacy, curiosity, self-management, and holistic thinking (Bölükbaş, 2024). By integrating Art into STEM subjects, STEAM fosters a learning environment that capitalizes on students' natural inclination toward creative exploration (Johnston & Kervin, 2022; DeJarnette, 2018). Consequently, STEAM curricula effectively boost student motivation and deepen learning through hands-on experiences that make real-world connections (Wahyuningsih et al., 2020a; Cook et al., 2020).

Numerous studies also underscore the importance of STEAM approaches in early childhood education, given young learners' innate curiosity and willingness to experiment (DeJarnette, 2018; Wahyuningsih et al., 2020b). Activities that leverage flexible materials or thematic play not only enhance cognitive development but also promote social-emotional growth (Garner et al., 2017; Budiyanto et al., 2021). Overall, STEAM education holistically fosters a range of competencies, preparing learners to meet the demands of the 21st-century workforce and society (Johnston & Kervin, 2022; Wahyuningsih et al., 2020).

1.3. Artificial Intelligence and Generative AI: Key Concepts

Artificial Intelligence (AI) refers to computer systems designed to replicate human-like cognitive functions, including learning, problem-solving, and decision-making (Russell & Norvig, 2021). Originating from the pioneering work of Alan Turing in the 1950s (Carricho, 2018), AI has undergone rapid evolution in recent years, driven by innovations in machine learning and deep learning. These advancements have enabled computers to process vast amounts of data and autonomously adapt decision-making processes (Ece, 2024). AI literacy an emerging concept advocates for an informed understanding of AI's capabilities and limitations, ensuring its ethical and responsible application (Elçiçek, 2024).

Generative AI (GAI) is a distinct subfield of AI that specializes in producing new content such as text, images, or music derived from existing datasets (Liu, 2023; Vafadar & Amani, 2024). Unlike conventional AI, which often focuses on solving specific tasks through data-driven insights, GAI emphasizes creative outputs (Ma, 2022). While AI typically targets analytical problem-solving and optimization, GAI delivers innovative solutions and original creations (Bryndin, 2019). This attribute renders GAI particularly valuable in creative domains such as arts, design, and education, where the generation of novel ideas or artifacts is paramount.

1.4. The Role of AI and Generative AI Tools in STEAM Education

AI and GAI tools increasingly occupy a central position in STEAM education by enhancing students' creative and analytical skill sets. These technologies can transform traditional learning environments by allowing deeper exploration of complex concepts, personalized learning trajectories, and data-driven feedback (Chen et al., 2020). AI-powered systems can analyze student performance in real time, adapt content, and present customized problem sets to optimize individual learning outcomes (Chen et al., 2020; Niu et al., 2022). Generative AI, on the other hand, enriches STEAM projects by supporting the creation of digital art, music compositions, and simulations. Students can develop both creative abilities and technical prowess, bridging disciplines such as engineering and design (Koul et al., 2022). Engaging with AI and GAI tools also cultivates students' algorithmic thinking skills, reinforcing the STEAM philosophy of integrated problem-solving. Consequently, these platforms help educators scaffold intricate concepts and foster learning experiences that resonate with a diverse set of learners (Kim & Kim, 2022).

Crucially, AI and GAI tools promote personalized, student-centered learning while enabling teachers to provide individualized guidance (Relmasira, 2023). Educators can leverage these platforms to develop or refine pedagogical strategies that cater to different learning styles, resulting in more efficient and meaningful educational outcomes (Cook et al., 2020; Hapidin et al., 2020). Despite their transformative potential, the adoption of AI and GAI comes with responsibilities, including data privacy, algorithmic fairness, and the need for robust teacher training (Klímová et al., 2023; Ayanwale, 2024).

1.5. Pedagogical Approaches and Professional Development

AI integration in STEAM education calls for educators who possess both subject-matter expertise and AI literacy (Elçiçek, 2024). Continuous professional development (CPD) programs are essential to support teachers in confidently using AI-based educational tools and guiding students in a technology-driven learning environment. Studies have shown that these tools significantly improve student engagement and learning outcomes, yet their effectiveness depends greatly on teachers' capacity to integrate AI solutions effectively into curricula (Niu et al., 2022; Chen, Huang & Chen, 2020).

Trust also plays a crucial role: educators must trust AI systems to be fair, reliable, and beneficial to student development (Ayanwale, 2024). By emphasizing the pedagogical benefits and offering hands-on training, educators can establish a constructive relationship with AI technologies. Additionally, the ethical implications of AI, such as bias and privacy concerns, should be addressed through well-structured guidelines and transparent data practices (Klímová et al., 2023).

1.6. AI Tools for STEAM Education

In Table 1, various AI tools and their functions, along with example scenarios in STEAM education, are presented. Table 1 clearly illustrates the various AI tools used in STEAM education and how these tools can be integrated into educational processes. Each tool enhances the learning experience by providing personalized learning, robust analytical support, or adaptive tutoring, thereby making the learning process more effective and efficient. These tools enable educators to create lesson content tailored to the needs of students and allow for progression based on individual learning paces. The potential of AI technologies in the STEAM field presents significant opportunities for advancing innovation in education.

Tablo 1. *AI Tools in STEAM Education*

AI Tool	Function	Example Scenario in STEAM Education	Access Link
IBM Watson Education	AI-powered personalized learning	A middle school science teacher uses IBM Watson to analyze student assessments, providing personalized feedback to support struggling learners.	IBM Watson Education
Google AI for Education	AI tools for natural language processing & analytics	A history teacher integrates Google AI's natural language processing tools to help students analyze historical texts and generate summaries.	Google AI for Education
CogniTutor	AI-based adaptive tutoring	A math teacher assigns CogniTutor to students struggling with algebra. The platform identifies weak areas and provides customized exercises.	CogniTutor
Querium	AI-enhanced STEM learning	A physics teacher uses Querium's AI-driven tutoring system to help students master kinematics through step-by-step problem-solving guidance.	Querium
Century Tech	AI-driven personalized education pathways	A high school computer science class uses Century Tech to track student progress in Python programming and adjust learning materials accordingly.	Century Tech
Squirrel AI Learning	Adaptive AI learning	In a flipped classroom setting, Squirrel AI assigns customized pre-class learning modules based on individual student performance.	Squirrel AI Learning
Python	Programming for AI & machine learning	Students in a computer science course use Python and TensorFlow to build a simple AI model that classifies handwritten digits.	Python
Jupyter Notebook	Interactive coding & data visualization	A statistics class uses Jupyter Notebook to analyze climate change data and visualize trends using Python libraries.	Jupyter Notebook
TensorFlow	Machine learning framework	An engineering class builds a neural network in TensorFlow to classify images of different bridge structures for structural analysis.	TensorFlow
PyTorch	Deep learning framework	A university AI lab utilizes PyTorch for a student-led project on self-driving car simulations, training AI models on real-world datasets.	PyTorch
R Programming	Statistical computing & AI modeling	A data science course applies R to analyze student performance trends and predict success in STEAM subjects.	R Programming

2. Generative AI Tools for STEAM Education

The following table presents various generative AI tools for STEAM education, along with their functions, example scenarios in STEAM education, and access links.

Tablo 2. *Generative AI Tools in STEAM Education*

Generative AI Tool	Function	Example Scenario in STEAM Education	Access Link
Code.org	Enhances computer science and coding skills through interactive lessons and games.	A middle school teacher uses Code.org's interactive lessons to teach students foundational coding concepts and logic.	Code.org
ChatGPT (OpenAI)	Assists with writing, problem-solving, and coding tasks; transforms learning processes in diverse settings.	Students use ChatGPT to brainstorm ideas, solve coding challenges, and receive real-time feedback during their computer science class.	ChatGPT
Bing Chat (Microsoft)	An AI-assisted chat platform offering STEM-related information and interactive learning.	A high school physics teacher uses Bing Chat to facilitate interactive discussions on complex topics like quantum mechanics and relativity.	Bing Chat
Google AI Tools (e.g., Quick Draw, Auto Draw)	Facilitates AI-driven content creation in arts education, inspiring student creativity.	In an art class, students use Google's Quick Draw to explore AI-based drawing prompts, enhancing their creativity and artistic skills.	Google AI Tools
Augmented Reality (AR) and Virtual Reality (VR) Tools (e.g., Google Expeditions)	Immersive tools that help students comprehend complex concepts through interactive learning experiences.	Students use Google Expeditions in a history class to virtually explore ancient civilizations, deepening their understanding through immersive experiences.	Google Expeditions
AI-Powered Educational Platforms (e.g., Khan Academy, Coursera)	Adjust content to student performance for a personalized, adaptive learning experience.	A biology student uses Khan Academy to progress through personalized lessons on genetics and cell biology, adjusting content based on their learning pace.	Khan Academy
AI Chatbots	Provide immediate feedback and resources, thereby increasing interactivity in learning.	Students use AI chatbots to get quick answers to questions while working on STEM projects, improving engagement and learning efficiency.	AI Chatbots
Learning Analytics Dashboards	Optimize teaching strategies by analyzing student data and identifying growth areas.	A teacher uses learning analytics dashboards to track student progress in chemistry and adapt teaching strategies accordingly.	Learning Dashboards
Canva	Encourages the development of communication and design skills by enabling user-friendly graphic creation.	In a design class, students use Canva to create infographics about climate change, combining art and science to visualize data.	Canva
DALL•E (OpenAI)	Generates original visual content, empowering students to explore creativity in art and design projects.	Students use DALL•E to generate unique illustrations for a storytelling project, enhancing their visual design and narrative skills.	DALL•E
DeepArt.io	Transforms existing images into artistic renditions, helping students learn about different art styles.	In an art history class, students use DeepArt.io to transform photographs into famous art styles, exploring visual storytelling techniques.	DeepArt.io

Runway ML	Allows the development of digital art, animations, and graphic designs via deep learning models.	Students in a media arts class use Runway ML to create short animations that explain the principles of physics, such as motion and energy.	Runway ML
Soundraw	Enables the AI-driven composition of music, fostering creativity and self-expression.	A music class uses Soundraw to compose original soundtracks for a film project, learning about music production and digital composition.	Soundraw
Miro AI	Supports brainstorming, ideation, and collaborative content creation in group projects.	In a group project, students use Miro AI to collaborate on designing a robotic prototype, utilizing brainstorming tools and AI suggestions.	Miro AI
GPT-3 API (OpenAI)	Allows students to develop custom AI applications such as chatbots and text-generation platforms.	Students use GPT-3 to create a chatbot for a language learning project, enhancing their programming skills and understanding of AI concepts.	GPT-3 API
StableDiffusion	An open-source GAI model for generating original images, applicable in various art projects.	In an art class, students use StableDiffusion to generate illustrations based on prompts that reflect their creative interpretation of a theme.	StableDiffusion
Artbreeder	Merges multiple visuals to create unique artwork, useful for exploring concepts of genetics and artistic variation.	Students in a biology class use Artbreeder to create visual representations of genetic traits and inheritance patterns.	Artbreeder
Craiyon (formerly DALL•E Mini)	Generates images from textual prompts, providing a user-friendly tool for design exercises.	A graphic design student uses Craiyon to create concepts for a new product design, experimenting with different visual styles.	Craiyon
Magenta (Google)	Facilitates the creation of music and art through AI, enabling students to experiment with digital media.	Students use Magenta to compose music and generate visual art, exploring how AI can intersect with creativity in a multimedia project.	Magenta
DeepDream (Google)	Uses image recognition algorithms to produce abstract and fantastical transformations of standard photos.	In an art class, students use DeepDream to create surreal images from photographs, learning about algorithms and creative expression.	DeepDream
JukeBox (OpenAI)	Analyzes music patterns and generates new songs, helping students understand and explore musical structures.	Music students use JukeBox to analyze musical trends and compose new pieces in various genres, learning about music theory and composition.	JukeBox
Scribbl (Google)	Enhances simple sketches with AI-generated artistic details, acting as a source of inspiration in art classes.	Art students use Scribbl to refine their sketches by adding AI-generated details, improving their understanding of design and creativity.	Scribbl
ThisPersonDoesNotExist	Generates fictional human faces, beneficial for character design and digital storytelling projects.	Students use ThisPersonDoesNotExist to create fictional characters for a digital storytelling project, learning about character design principles.	ThisPersonDoesNotExist

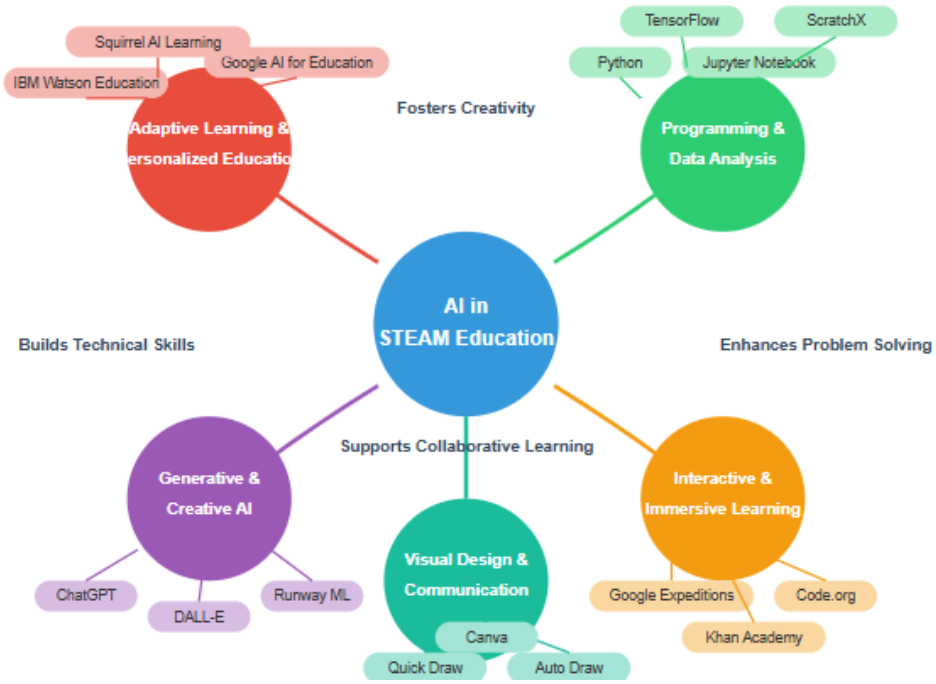
Pikazo	Reimagines photographs in the style of famous painters, facilitating the study of art history and design.	Art history students use Pikazo to explore and recreate famous paintings, learning about different artistic styles and techniques.	Pikazo
AIVA (Artificial Intelligence Virtual Artist)	Composes original music in various styles, allowing students to experiment in music composition.	In a music class, students use AIVA to compose music for a multimedia project, experimenting with various styles and genres.	AIVA
PictoBlox	A block-based coding environment tailored to AI and robotics, ideal for beginners.	Students in a robotics class use PictoBlox to program robots for AI-based tasks, learning basic coding and robotics concepts.	PictoBlox
mBlock	Integrates Scratch-based coding with AI and machine learning, streamlining the creation of entry-level AI projects.	Students use mBlock to create simple AI projects, such as a chatbot or automated system, helping them grasp basic machine learning concepts.	mBlock
ScratchX AI Extensions	Extends the Scratch platform to incorporate AI functionalities, simplifying basic AI concept exploration.	A coding class uses ScratchX to build interactive projects, exploring the integration of AI features like speech recognition and computer vision.	ScratchX
Codey Rocky (Makeblock)	Combines robotics and AI, giving students hands-on experience in programming physical hardware for AI tasks.	Students use Codey Rocky to create and program robots for AI tasks, applying their knowledge of both coding and robotics in practical scenarios.	Codey Rocky
Teachable Machine (Google)	Allows users to collect data and train AI models using intuitive, block-based programming.	Students use Teachable Machine to train AI models to recognize images or sounds, learning the fundamentals of AI and machine learning.	Teachable Machine

Table 2 illustrates how generative AI tools used in STEAM education can be integrated into teaching processes and their role in education. These tools enable students to develop creative thinking and problem-solving skills in areas such as coding, art, music, robotics, and artificial intelligence, while also offering teachers the opportunity to provide customized content based on individual learning speeds. AI-powered tools facilitate the application of theoretical knowledge, allowing students to creatively use technology and promoting deep, interdisciplinary learning experiences.

2.1. Innovative Groupings of AI Tools for STEAM Education

Modern STEAM curricula increasingly require educators to employ a variety of AI tools tailored to different learning objectives. By systematically grouping these tools based on their unique functionalities, educators can more effectively pinpoint the resources that best suit their lesson goals. From adaptive learning systems to creative generative AI, each category plays a vital role in enriching student engagement and understanding. The paragraphs below explore each grouping in more detail, explaining how these specialized tools can elevate STEAM education. In the concept map, the AI tools have been systematically categorized to reflect their primary functions and how they can be applied within STEAM education. Rather than listing the tools randomly, the grouping is based on the specific features each platform or library offers ranging from adaptive learning systems and programming frameworks to generative creativity tools. The goal is to make it easier for educators and researchers to identify which tools best align with the learning outcomes they aim to achieve in various STEAM activities.

Figure 1. *A concept map of AI and STEAM Education correlations with five categories.*



Adaptive Learning & Personalized Education tools (e.g., IBM Watson Education, Google AI for Education, and Squirrel AI Learning) adapt content to a student's current level of understanding. In STEAM contexts, this is particularly important because learners often have varying degrees of skill in mathematics, coding, and project-based engineering tasks. Tools that personalize learning ensure that students move at a suitable pace, receiving additional support or accelerated challenges as needed. This model not only keeps students engaged but also frees up instructors to focus on activities that foster creativity and higher-order problem-solving.

Shifting to **Programming & Data Analysis**, platforms like Python, Jupyter Notebook, and TensorFlow form the backbone of computational thinking in STEAM education. They enable students to write code that models scientific phenomena, automates engineering processes, and even generates data-driven visual art. For younger or less experienced learners, block-based environments such as mBlock and ScratchX AI Extensions—lower the entry barrier. Instead of grappling with syntax, students can experiment with fundamental AI and robotics concepts, which fosters confidence and prepares them for more advanced coding challenges.

Meanwhile, **Generative & Creative AI** services (ChatGPT, DALL-E, Runway ML, and others) serve as catalysts for innovative projects that merge art with technology. Learners can craft AI-generated music, create one-of-a-kind visuals for geometry lessons, or even build story scenarios that illustrate scientific principles. By prompting students to work in this hybrid zone of digital creativity, educators invite them to cultivate not just technical expertise but also an appreciation for aesthetics, design thinking, and imaginative storytelling key ingredients of the "A" in STEAM.

For immersive experiences, **Interactive & Immersive Learning** tools like Google Expeditions, Code.org, and Khan Academy offer virtual and augmented reality modules, coding exercises, and self-paced educational tracks. These tools help students visualize abstract concepts such as molecular structures or physics simulations and encourage active learning through gamified challenges. By embedding real-time feedback and progress tracking, they sustain learners' motivation and allow teachers to pinpoint areas where further intervention or extension activities may be needed.

Finally, **Visual Design & Communication** solutions (Quick Draw, Auto Draw, Canva) highlight the importance of aesthetic presentation and clear communication in STEAM. Whether students are showcasing experiment data, designing engineering prototypes, or curating an art-and-technology gallery, these tools enable them to articulate their findings compellingly. As modern workplaces value both technical

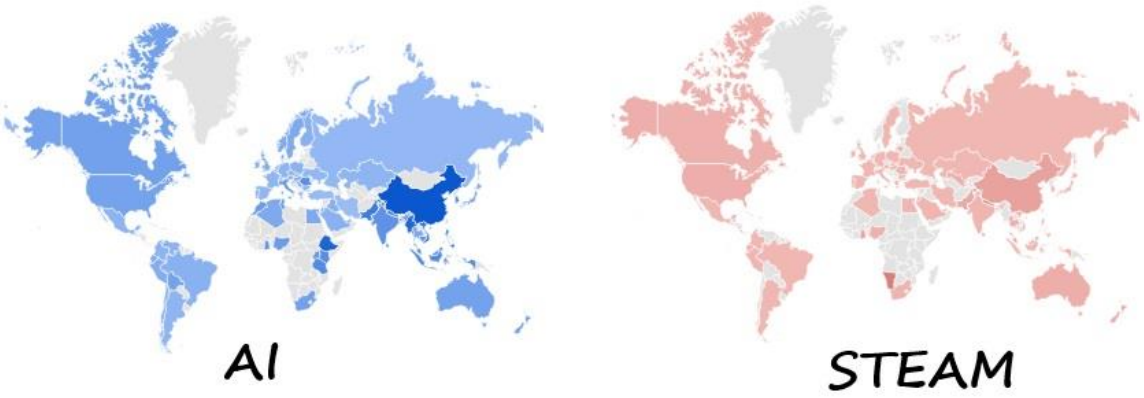
competencies and effective storytelling, mastering visual communication ensures that students' ideas resonate with broader audiences, be it in professional conferences or school-wide exhibitions.

Overall, categorizing AI tools in this way provides a holistic roadmap for educators to integrate technology seamlessly into the STEAM environment. Each subcategory caters to a unique facet of learning—from adaptive support to creative expression ensuring that students develop a broad spectrum of skills. By exploring these tools strategically, teachers can craft lessons that highlight the connections between scientific inquiry, technological innovation, engineering problem-solving, artistic creativity, and mathematical reasoning, preparing learners for the multifaceted challenges of the 21st century.

2.2. Bridging AI and STEAM Education: Emerging Trends and Synergies

Recent data from Google Scholar indicates that there are about 7.99 million articles featuring "AI" in their titles, compared to 2.72 million documents focusing on "STEAM education." Despite the apparent discrepancy in sheer volume, both concepts demonstrate robust academic interest and continue to gain traction in educational research. AI has long been hailed as a transformative technology across industries, while STEAM education emphasizes an interdisciplinary approach integrating science, technology, engineering, arts, and mathematics to foster critical thinking and creativity. These parallel evolutions point toward a growing recognition that modern education must address the demands of a world shaped by rapid technological advancement. Furthermore, a Google Trends analysis comparing searches for "AI" and "STEAM education" reveals an 87% correlation, suggesting that as public interest in one concept rises, the other tends to follow a similar trajectory (Figure 1). This relationship underscores the increasingly intertwined nature of technological innovation and holistic educational frameworks. Scholars and practitioners alike appear to be seeking ways to merge AI's computational power with STEAM's hands-on, project-based learning strategies. In doing so, they aim to equip learners not only with technical expertise but also with creative problem-solving skills that transcend disciplinary boundaries.

Figure 2. *Search comparisons of the concepts of AI and STEAM education*



The strong correlation and mounting academic references signal a critical juncture: as AI continues to evolve at breakneck speed, STEAM education must adapt to integrate AI-driven tools and methodologies. Incorporating AI in STEAM curricula can spark greater student engagement, hone analytical thinking, and nurture artistry collectively preparing learners for 21st-century challenges. By uniting these two arenas, educators and policymakers can foster a generation of innovators capable of leveraging AI's potential in ethically responsible and creatively inspired ways.

3. CONCLUSION

AI and Generative AI (GAI) are revolutionizing STEAM (Science, Technology, Engineering, Arts, and Mathematics) education by making learning experiences more interactive, personalized, and creative. Recent Google Trends data, for instance, reveals a significant correlation—over 80%—between searches for "AI" and "STEAM education," underscoring a growing, interconnected public interest in both topics. As AI tools continue to evolve, they offer a powerful means to tackle complex STEAM concepts, encouraging students to forge interdisciplinary connections and develop problem-solving skills vital for the 21st-century workforce (Johnston & Kervin, 2022; DeJarnette, 2018; Wahyuningsih et al., 2020). These tools not only present information to students but also challenge them to think critically and creatively, applying their knowledge to real-world problems. For example, students can use AI-powered software to develop solutions to engineering problems and then relate these solutions to practical applications in the real world. These experiences allow students to enhance both their theoretical knowledge and practical skills (Chen & Gutmann, 2019; ,Marar, 2024).

Nevertheless, the incorporation of AI into STEAM curricula requires strategic planning and close attention to ethical considerations such as fairness, privacy, and inclusivity (Klímová et al., 2023). It is essential that educators receive training not only on how to use AI tools but also on how to identify and mitigate biases that may exist in algorithmic processes. Ethical training should also guide educators in making sure that resources are distributed equitably so that all students can benefit from these innovations (Yazıcı & Erkoç, 2023; Sincar, 2023). Beyond the technological affordances of AI and GAI, educators must also address issues of bias in algorithmic processes, data protection, and equitable resource distribution to ensure that all learners can benefit from these innovations. By aligning professional development with these concerns, teachers can learn to recognize, mitigate, and responsibly manage potential pitfalls while maximizing the pedagogical strengths of AI-driven platforms (Ayanwale, 2024). In this context, it is also crucial for educators to not only understand how to use AI tools but also how to consider the broader societal impact of these technologies. Teachers should receive more guidance on recognizing and addressing the ethical challenges of AI in the classroom (Pan, 2024).

Ongoing professional development for educators, transparent policy guidelines, and robust institutional support are essential for fully realizing the benefits of AI and GAI in STEAM education. Structured professional development programs that help teachers use AI tools securely and effectively will boost their confidence and skills. Creating platforms for teachers to share their experiences with AI can help spread best practices and facilitate collaboration (Semwaiko et al., 2024). Future research could delve into the long-term learning outcomes and motivational impacts of AI-based interventions, as well as explore strategies for fostering teacher capacity and confidence in effectively leveraging AI tools for different age groups. In particular, analyzing the long-term motivational effects of AI interventions will be critical in determining whether these technologies enhance students' engagement with learning. Expanding on existing studies, researchers might also investigate how AI-mediated approaches influence career trajectories and STEAM skill retention over time (Becker & Park, 2011). Additionally, larger-scale policy initiatives and cross-sector collaborations can further strengthen AI and GAI integration. Policymakers, industry partners, and educational institutions should work together to develop shared guidelines and standards, ensuring that these technologies are ethically applied. On a national level, there should be collaborative policies developed to strengthen AI education, which will shape not only the educators but also the way students interact with AI (Kim et al., 2022.) By prioritizing transparency in algorithmic decision-making and accessibility in resource allocation, stakeholders can better address the digital divide and extend AI-driven opportunities to underserved communities (Noble, 2018).

Ultimately, the synergy between AI/GAI and STEAM education signifies an evolving pedagogical landscape one in which creativity, technological fluency, and real-world problem-solving abilities converge. This synergy is not just about academic achievement but also about preparing students with lifelong skills such as critical thinking and creative problem solving. By working with AI tools, students can develop solutions to real-world problems, enhancing their practical and theoretical learning. As the correlation in public interest suggests, learners, educators, and societies at large are ready to embrace AI's transformative potential. By continuously refining these tools and pedagogical strategies, stakeholders can equip students with the critical, creative, and collaborative skill sets necessary to thrive in an increasingly interconnected global society

(Saavedra & Opfer, 2012). In this developmental process, it is important to collaborate with educators to ensure that AI tools are used effectively and that students are getting the most out of their learning experience.

4. RECOMMENDATIONS

Future research and educational policies should focus on areas such as the long-term effects of integrating AI and Generative AI (GAI) into STEAM education, teachers' confidence and competence in using AI tools, and ethical and equity considerations. Studies should investigate the long-term impacts of AI-based interventions on students' learning outcomes, motivation, and retention of STEAM skills, while also enhancing professional development programs to ensure that teachers are well-equipped to use these tools effectively. Educational policies must establish clear guidelines for the ethical use of AI tools in education, addressing issues such as algorithmic bias, data security, and equitable access to resources. Furthermore, robust infrastructure should be developed to ensure that all schools have access to these tools. Additionally, the role of AI education in preparing students for their careers should be explored, and policies should be formulated to develop skills aligned with workforce needs, ensuring that students are adequately prepared for future job markets.

Acknowledgments

This study has not been presented at any conference and does not originate from a thesis. No financial support was received from any institution or organization during the preparation of this study.

Declaration of Conflicting Interests and Ethics

The authors declare that there is no conflict of interest regarding this study. The research has been conducted in accordance with the principles of scientific research and publication ethics. The scientific and legal responsibility for the content published in IJEDAI lies with the authors. As this study is a literature review, it does not require approval from an ethics committee.

Authorship Contribution Statement

First Author: Contributed to the literature review and writing process.
Second Author: Contributed to the literature review and writing process.
Third Author: Took part in the final revision, writing process, editing, and approval of the manuscript.

REFERENCES

Aniskin, V., Korostelev, A., Львовна, Б., Kurochkin, A., & Sobakina, T. (2020). Teaching potential of integrated learning technologies smart, stem and steam. *Revista De La Universidad Del Zulia, 11(29),* 328-336. https://doi.org/10.46925//rdluz.29.21

Ayanwale, M. (2024). Exploring steam teachers' trust in ai-based educational technologies: a structural equation modelling approach. *Discover Education, 3(1).*https://doi.org/10.1007/s44217-024-00092-z

Belda-Medina, J. (2024). Ai-driven digital storytelling: a strategy for creating english as a foreign language (efl) materials. *International Journal of Linguistics Studies, 4(1),* 40-49. https://doi.org/10.32996/ijls.2024.4.1.4

Bölükbaş, E. (2024). *STEAM alan öğretmenlerinin robotik ve kodlama eğitimi için tasarlanan ters yüz öğrenme ortamına ilişkin görüşleri ve akademik başarıları* [Yüksek Lisans Tezi]. Bursa Uludağ Üniversitesi.

Bryndin, E. (2019). Practical development of creative life-saving artificial intelligence. *Communications, 7(2),* 31. https://doi.org/10.11648/j.com.20190702.11

Budiyanto, C., Shahbodin, F., Umam, M., Isnaini, R., Rahmawati, A., & Widiastuti, I. (2021). Developing computational thinking ability in early childhood education: the influence of programming-toy on parent-children engagement. *International Journal of Pedagogy and Teacher Education, 5(1),* 19. https://doi.org/10.20961/ijpte.v5i1.44397

Carriço, G. (2018). The eu and artificial intelligence: a human-centred perspective. *European View, 17(1),* 29-36. https://doi.org/10.1177/1781685818764821

Chen, L., Chen, P., & Lin, Z. (2020). Artificial intelligence in education: a review. *IEEE Access, 8,* 75264-75278. https://doi.org/10.1109/access.2020.2988510

Chen, W., Huang, C., & Chen, K. (2020). Artificial intelligence in education: from potential to practice. *Educational Technology & Society, 23(3),* 24-36.

Chen, X., & Gutmann, G. (2019). Deep learning by doing: The NVIDIA deep learning institute and university ambassador program. *The Journal of Computational Science Education, 10*(1), 93–99. https://doi.org/10.22369/issn.2153-4136/10/1/16

Cook, K., Bush, S., Cox, R., & Edelen, D. (2020). Development of elementary teachers' science, technology, engineering, arts, and mathematics planning practices. *School Science and Mathematics, 120(4),* 197-208. https://doi.org/10.1111/ssm.12400

DeJarnette, N. (2018). Implementing steam in the early childhood classroom. *European Journal of Stem Education, 3(3).*https://doi.org/10.20897/ejsteme/3878

Delcker, J. (2024). First-year students' ai-competence as a predictor for intended and de facto use of ai-tools for supporting learning processes in higher education. *International Journal of Educational Technology in Higher Education, 21(1).*https://doi.org/10.1186/s41239-024-00452-7

Ece, N. (2024). Yapay zeka: denizcilik sektöründe kullanımı ve swot analizi. *Mersin Üniversitesi Denizcilik Ve Lojistik Araştırmaları Dergisi, 6(1),* 30-51. https://doi.org/10.54410/denlojad.1491372

Elçiçek, M. (2024). Öğrencilerin yapay zeka okuryazarlığı üzerine bir inceleme. *Bilgi Ve İletişim Teknolojileri Dergisi, 6(1),* 24-35. https://doi.org/10.53694/bited.1460106

Erol, A. (2023). STEAM eğitimi sürecinde okula hazır oluş. *Uluslararası Eğitim Bilimleri Dergisi, 10 (36),* 298-325.

Garner, P., Gabitova, N., Gupta, A., & Wood, T. (2017). Innovations in science education: infusing social emotional principles into early stem learning. *Cultural Studies of Science Education, 13(4),* 889-903. https://doi.org/10.1007/s11422-017-9826-0

Gunarti, W., Pujianti, Y., & Syarah, E. (2020). Steam to r-slamet modification: an integrative thematic play based learning with r-slamets content in early child-hood education. *Jpud - Jurnal Pendidikan Usia Dini, 14(2),* 262-274. https://doi.org/10.21009/jpud.142.05

Henze, J., Schatz, C., Malik, S., & Bresges, A. (2022). How might we raise interest in robotics, coding, artificial intelligence, steam and sustainable development in university and on-the-job teacher training?.*Frontiers in Education, 7.*https://doi.org/10.3389/feduc.2022.872637

Hsiao, P.,& Su, C. (2021). A study on the impact of steam education for sustainable development courses and its effects on student motivation and learning. *Sustainability, 13(7),* 3772. https://doi.org/10.3390/su13073772

Hsu, T., Abelson, H., Lao, N., & Chen, S. (2021). Is it possible for young students to learn the ai-steam application with experiential learning?.*Sustainability, 13(19),* 11114. https://doi.org/10.3390/su131911114

Huang, J., Saleh, S., & Liu, Y. (2021). A review on artificial intelligence in education. *Academic Journal of Interdisciplinary Studies, 10(3),* 206. https://doi.org/10.36941/ajis-2021-0077

Ishaaq, N. (2023). Re: investigating the impact of innovative ai chatbot on post-pandemic medical education and clinical assistance: a comprehensive analysis. *Australian and New Zealand Journal of Surgery, 94(3),* 494-494. https://doi.org/10.1111/ans.18721

Johnston, K.,& Kervin, L. (2022). Stem, steam and makerspaces in early childhood: a scoping review. *Sustainability, 14(20),* 13533. https://doi.org/10.3390/su142013533

Kim, J., Lee, H., & Cho, Y. H. (2022). Learning design to support student-AI collaboration: Perspectives of leading teachers for AI in education. *Education and Information Technologies, 27*(5), 6069–6104. https://doi.org/10.1007/s10639-021-10831-6

Kim, N.,& Kim, M. (2022). Teacher's perceptions of using an artificial intelligence-based educational tool for scientific writing. *Frontiers in Education, 7.*https://doi.org/10.3389/feduc.2022.755914

Klímová, B., Pikhart, M., & Kacetl, J. (2023). Ethical issues of the use of ai-driven mobile apps for education. *Frontiers in Public Health, 10.*https://doi.org/10.3389/fpubh.2022.1118116

Koul, R., Lerdpornkulrat, T., & Poondej, C. (2022). Generative AI in STEAM education: Bridging creativity and technology. *Journal of Educational Research, 115(2),* 178-194.

Liu, Y. (2023). Implications of generative artificial intelligence for the development of the media industry. *AEI, 1(1),* 29-36. https://doi.org/10.54254//1/2023006

Luo, Q. (2023). The influence of ai-powered adaptive learning platforms on student performance in chinese classrooms. *Journal of Education, 6(3),* 1-12. https://doi.org/10.53819/81018102t4181

Ma, C. (2022). Generated artificial general intelligence—The philosophical principle of artificial general intelligence and give an example. *Available at SSRN 4224423.*https://doi.org/10.14293/s2199-1006.1.sor-.pph6xzb.v2

Marar, H. W. (2024). Advancements in software engineering using AI. *Computer Software and Media Applications, 6*(1), 3906. https://doi.org/10.24294/csma.v6i1.3906

Niu, S., Luo, J., Niemi, H., Li, X., & Lu, Y. (2022). Teachers' and students' views of using an ai-aided educational platform for supporting teaching and learning at chinese schools. *Education Sciences, 12(12),* 858. https://doi.org/10.3390/educsci12120858

Pan, J. (2024). AI-driven English language learning program and academic writing integrity in the era of intelligent interface. *English Language Teaching and Linguistics Studies, 6*(4), 120. https://doi.org/10.22158/eltls.v6n4p120

Relmasira, S. (2023). Fostering ai literacy in elementary science, technology, engineering, art, and mathematics (steam) education in the age of generative ai. *Sustainability, 15(18),* 13595. https://doi.org/10.3390/su151813595

Russell, S.,& Norvig, P. (2021). *Artificial Intelligence: A Modern Approach* (4th ed.). Pearson.

Semwaiko, G. S., Chao, W., & Yang, C. (2024). Transforming K-12 education: A systematic review of AI integration. *International Journal of Educational Technology and Learning, 17*(2), 43–63. https://doi.org/10.55217/101.v17i2.847

Sevgen Abacı, H.,& Tüzün, Ü. N. (2023). Özel Yetenekli Öğrencilerin Eğitiminde Bilim ve Sanat Entegresi. *Bilim Armonisi, 5(2),* 32-38. https://doi.org/10.37215/bilar.1144744

Sincar, M. (2023). Yapay zekâ bağlamında okul liderlerini bekleyen zorluklar. *Mustafa Kemal Üniversitesi Eğitim Fakültesi Dergisi, 7*(12), 74–85. https://doi.org/10.56677/mkuefder.1407065

Smyrnaiou, Z. (2023). Ethical use of artificial intelligence and new technologies in education 5.0. *JAIMLD, 1(4),* 119-124. https://doi.org/10.51219/jaimld/anastasios-liapakis/15

Spyropoulou, N. (2023). Augmenting the impact of steam education by developing a competence framework for steam educators for effective teaching and learning. *Education Sciences, 14(1),* 25. https://doi.org/10.3390/educsci14010025

Tsupros, N., Kohler, R., & Hallinen, J. (2009). *STEM education: A project to identify the missing components.* Intermediate Unit, 1, 11-17.

Tüzün, U.,& Tüysüz, C. (2018). Eğitimde stem + a yaklaşımı: fen eğitiminde steam uygulamaları. In *Fen ve Matematik Eğitiminde Araştırma ve Uygulamalar* (pp. 186-202).

Vafadar, M.,& Amani, A. M. (2024). Academic education in the era of generative artificial intelligence. *Journal of Electronics and Electrical Engineering,* 110-124. https://doi.org/10.37256/jeee.3120244010

Vasconcelos, M.,& Santos, R. (2023). Enhancing stem learning with chatgpt and bingchat as objects to think with: a case study. *Eurasia Journal of Mathematics Science and Technology Education, 19(7),* em2296. https://doi.org/10.29333/ejmste/13313

Vicente, F., Llinares, A., & Sánchez, N. (2020). "Sustainable city": a steam project using robotics to bring the city of the future to primary education students. *Sustainability, 12(22),* 9696. https://doi.org/10.3390/su12229696

Wahyuningsih, S., Nurjanah, N., Rasmani, U., Hafidah, R., Pudyaningtyas, A., & Syamsuddin, M. (2020a). Steam learning in early childhood education: a literature review. *Ijpte International Journal of Pedagogy and Teacher Education, 4(1),* 33. https://doi.org/10.20961/ijpte.v4i1.39855

Wahyuningsih, S., Pudyaningtyas, A., Nurjanah, N., Dewi, N., Hafidah, R., Syamsuddin, M., … & Sholeha, V. (2020b). The utilization of loose parts media in steam learning for early childhood. *Early Childhood Education and Development Journal, 2(2),* 1. https://doi.org/10.20961/ecedj.v2i2.46326

Wardat, Y., Tashtoush, M., AlAli, R., & Jarrah, A. (2023). Chatgpt: a revolutionary tool for teaching and learning mathematics. *Eurasia Journal of Mathematics Science and Technology Education, 19(7),* em2286. https://doi.org/10.29333/ejmste/13272

Wu, D., Xiang, Y., Wu, X., Yu, T., Huang, X., Zou, Y., … & Liu, Z. (2020). Artificial intelligence-tutoring problem-based learning in ophthalmology clerkship. *Annals of Translational Medicine, 8(11),* 700-700. https://doi.org/10.21037/atm.2019.12.15

Yazıcı, S. Ç., & Erkoç, M. (2023). Fen bilimleri grubu öğretmenlerinin uzaktan eğitim sürecinde yapay zekâ kullanma durumlarının analizi. *Dokuz Eylül Üniversitesi Buca Eğitim Fakültesi Dergisi, 58*, 2682–2704. https://doi.org/10.53444/deubefd.1316144

Yilmaz, Y., Yılmaz, D., Yıldırım, D., Korhan, E., & Kaya, D. (2021). Yapay zeka ve sağlıkta yapay zekanın kullanımına yönelik sağlık bilimleri fakültesi öğrencilerinin görüşleri. *Süleyman Demirel Üniversitesi Sağlık Bilimleri Dergisi, 12(3),* 297-308. https://doi.org/10.22312/sdusbed.950372

Research Article https://doi.org/10.5281/zenodo.16615094

International Journal of Educational and Artificial Intelligence

Year 2025, Volume 2, Issue 1, page 17 - 40

ISSN: 3062-228X
http://www.ijedai.com/

Bibliometric analysis of formative assessment research in science education

Sibel Sadi Yılmaz

Dede Korkut Faculty of Education, Kafkas University, Kars, Türkiye

Article Info

Submitted: 13.01.2025
Accepted: 21.07.2025
Published Online: 30.07.2025

Keywords
Formative assessment
Science education
Bibliometric analysis
Machine learning

DOI
https://doi.org/10.5281/zenodo.16615094

*Corresponding Author:

Sibel Sadi Yılmaz

E-mail:
sibelsadiyilmaz@kafkas.edu.tr

Abstract

Purpose: The purpose of this study is to study a bibliometric analysis of articles within the scope of "formative assessment in science education"

Design and Methodology: This study was conducted according to bibliometric analysis which uses different qualitative and quantitative literature review methods to explore and analyze large volumes of scientific data obtained from previous studies. In this study, articles published in the "Web of Science", one of the most popular bibliographic databases containing 22,000 peer-reviewed journals worldwide, were examined. In this study, VOSviewer software and Biblioshiny developed in R language developed for bibliometric analysis were used.

Results: In the Web of Science, studies on formative assessment in science education have been published since 2001, while Turkey-based publications have been published since 2014. The most frequently published articles and citations on the subject appear to be in science education, teacher-focused, and technology-focused journals.

Implications & Suggestions: It can be argued that studies on formative assessment in science education have become increasingly widespread in recent years. Furthermore, considering the journals in which the articles are most frequently published, it can be argued that teachers and educational technologies are important factors in the formative assessment process in science education, and that teacher-focused, technology-supported studies will contribute to literature.

To cite this article:

Sadi Yılmaz, S. (2025). Bibliometric analysis of formative assessment research in science education. *International Journal of Educational and Artificial Intelligence, 2*(1), 17-40. https://doi.org/10.5281/zenodo.16615094

1. INTRODUCTION

Measurement is the representation of the degree to which living or non-living beings have a certain quality or characteristic with numbers or symbols within the framework of certain rules. Evaluation is the comparison of measurement results with criteria and reaching a decision about the measured characteristic. Measurement and evaluation studies in the field of education generally examine the cognitive, affective and motor behaviors of individuals (Atılgan et al., 2009). According to their functionality, evaluation activities that have an important place in the teaching process are diagnostic evaluation, formative evaluation, summative evaluation (Lawton et all, 2012; Menezes & De Bortolli, 2016; Bell & Cowie 2001). Diagnostic assessment is used at the beginning of the teaching process to determine the student's readiness level (Lawton et al., 2012; Menezes & De Bortolli, 2016; Bell & Cowie 2001), weaknesses and strengths (Terwase & Oluwatoyin, 2018).

With diagnostic assessment, areas where students need to learn can be determined. Organizing the teaching process according to these needs is very effective in developing students' knowledge and skills. (Terwase & Oluwatoyin, 2018). Formative evaluation, which aims to establish an effective learning-teaching process by determining the degree to which the student has reached the expected goals during the teaching period; and summative evaluation, which is carried out with the aim of determining the level reached at the end of the teaching (Lawton et et al., 2012; Menezes & De Bortolli, 2016; Bell & Cowie 2001). Summative evaluations, which provide general information about progress in education, are important for educators and politicians in terms of generally giving an idea about what kind of educational reforms should be made and how much budget should be allocated for education; formative evaluations carried out during the teaching process allow the student to have an idea about his/her own learning and the effectiveness of the learning activities provided by teachers. In this way, the teacher and the student can make arrangements in a more efficient way.

Formative evaluation in science education; Determining the extent to which the concepts that students construct in their minds overlap with scientifically accepted concepts is very important in terms of determining the student's ability to transfer/use the information they have learned to different situations and developing the teaching process accordingly (Bell & Cowie 2001; Shavelson et al., 2008). Scriven (1967) discussed formative assessment with the aim of improving the curriculum, and Bloom (1969) discussed it with the aim of providing continuous feedback and correction to students during the teaching process (Bennet, 2011). Grob et al (2017) drew attention to the importance of formative assessment in developing students' self-regulated learning ability.

Formative assessment: It aims to help students' conceptual understanding, attitude, motivation, effort for learning, explanation in the context of the learned subject and production of arguments about the subject (Dini et al., 2020) and to make the curriculum more effective (Cowie & Beverley, 1999). It can be said that the teaching process of teachers who use formative assessment practices effectively is more efficient (Dini et al., 2020). In a planned formative assessment, teachers should firstly reveal students' ideas about concepts (elicit), secondly reveal to what extent the essence of the targeted concept has been learned by the student (noticing substance / interpreting) and thirdly support the student's learning in order to direct his/her learning (Cowie et al., 2015; Levin et al., 2009). Support can also be obtained from experienced and successful teachers in the field in planning formative assessment activities and preparing questions (Adams & Wieman, 2010).

In order for conceptual understanding to occur in science classes, it is important to have qualitative questions in the formative assessment process in a classroom environment where students can express their opinions comfortably, reason, comment and transfer their knowledge to daily life events (Bulunuz & Bulunuz, 2013). Studies have shown that most science teachers use innovative, constructivist teaching methods effectively (İnaltun & Ateş, 2018), but they cannot use formative assessment practices effectively (Atasoy & Kaya, 2022; Bennet, 2011; İnaltun & Ateş, 2018). Some of the difficulties that teachers encounter in formative assessment practices are i- placing formative assessment practices in the teaching process, ii- content and structure of feedback, iii- students' interaction with feedback (Grob et al., 2017), crowded classes, and the difficulty of providing personalized feedback for each student (Buchanan, 2000; Hatziapostolou & Paraskakis, 2010; Hsu et al., 2011). Although developments in information and communication technologies contribute to the renewal and development of learning-teaching and assessment and evaluation activities inside and outside the school,

it is difficult to say that teachers who are accustomed to traditional and face-to-face teaching environments use technology effectively (Kamble et al., 2021). Sadi-Yılmaz & Yaşar, (2023) stated that the use of technology-supported formative assessment activities in science education has many advantages, but it also has some limitations and emphasized the importance of supporting teachers and teacher candidates in overcoming these limitations.

The purpose of this study is to conduct a bibliometric analysis of articles published within the scope of "formative assessment in science education" in Web of Science, one of the most popular bibliographic databases containing articles from 22,000 peer-reviewed journals worldwide (European University Institute, 2025), using the free and uncoded software VosViewer, R Studio, and bibliometrix/biblioshiny. This aims to present the research conducted in the field of "formative assessment in science education" to readers in a holistic manner.

Over time, scholars have resorted to various quantitative and qualitative methods to understand and organize the research done in previous years on a certain topic. Among these, bibliometrics is based on systematic, transparent, and repeatable measurements based on the measurement of scientific activities. However, bibliometric analyses are seen as a difficult process for some researchers because they require the use of a large number and variety of analysis and mapping software (Aria & Cuccurullo, 2017). The Vosviewer software used in the bibliometric analysis in this study can reveal co-authorship networks, citation-based networks, and concurrency networks based on data downloaded from Web of Science, Scopus, Dimensions, and Lens (Vosviewer, 2025). Additionally, with VOSviewer Online, visualizations of bibliometric networks can be examined interactively in a web browser (LeidenMatrics, 2025). Another software tool used in this study; Biblioshiny, developed in the R language, imports data from databases such as SCOPUS, Web of Science, and PubMed, enabling co-citation, scientific collaboration analysis, and co-word analysis, as well as bibliometric analysis (Bibliometrix, 2025). The reason for using two different software programs in this study is that each software creates unique visuals using existing data. This study aimed to provide a richer mapping analysis of the data.

2. METHOD

2.1. Research Model

This study was conducted according to bibliometric analysis (Aria &, Cuccurullo, 2017), which uses different qualitative and quantitative literature review methods to explore and analyze large volumes of scientific data obtained from previous studies. Bibliometric analysis is used to reveal the general trends and components of a topic in articles, journals, etc. Bibliometric analysis can be done in the form of i- performance analysis, which addresses the contributions of research components, and ii- mapping, which focuses on the relationships between research components (Donthu et al., 2021).

2.2. Study Group

This research was conducted in the “Web of Science” database in the “Web of Science Core Collection” area. The search was conducted by analysing 213 articles that were accessed as a result of the search using the document type “article”, “Web of Science Categories”, “Refine by Citation Topic Meso” and “Refine by Citation Topics Micro” options.

2.3. Data Collection and Analysis Process

Within the scope of this study, 146 documents were reached in the search conducted on 23.09.2024 in the Web of Science database with the keywords "formative assessment" and "science education" in the "Web of Science Core Collection" field on formative assessment in science education (Appendix, Figure 4). In order to increase the validity of the study, the opinions of two experts in the field were taken and the keyword group "formative assessment" and ("science education" or "science learning" or "science teaching" or "science teacher" or "science student" or "biology education" or "biology learning" or "biology teaching" or "biology teacher" or "chemistry education" or "chemistry learning" or "chemistry teaching" or "chemistry teacher" or "physics education" or "physics learning" or "physics teaching" or "physics teacher" or "science curriculum" or "biology

curriculum" or "chemistry curriculum" or "physics curriculum" or "physics curriculum" was created. As a result of the search made with the keyword group, 304 documents were reached (Appendix, Figure 6). In determining the documents to be analysed, 213 articles (Appendix, Figure 14) were included in the analysis because of the inclusion of some criteria and the exclusion of some criteria. The data collection process is given in Table 1.

Table 1. *Data Collection Process*

Obtaining data from the database	As a result of the search conducted with the relevant keyword group from the "Topic" option of the WoS Core Collection database, 304 studies were reached (Appendix, Figure 6).
Refining the data	When the "article" option was selected from the "Documant types" section, 233 articles were reached on the subject. With the options selected from "Web of Science Categories", "Refine by Citation Topic Meso" and "Refine by Citation Topics Micro", 213 articles were reached at the end of the scan (Appendix, Figure 14), and these 213 articles were included in the analysis.

In line with the purpose of the study, the research titles and the applications used in the analysis of the data obtained from WosCC are listed in Table 2.

Table 2. *Research Titles and Applications to be Used in the Analysis of Related Titles*

	Research Titlles	Applications used in data analysis	Table, Figure, Graph No.
1	Number of articles published and number of citations by year	*	Graph 1
2	The most published and cited journals	***	Graph 2, Graph 3
3	Most cited articles	*	Table 3
4	Authors with the most articles	*	Graph 4
5	Articles published from Turkey on the subject	*	Table 4
6	Co-authorship of authors	**	Figure 1
7	Citation of authors	**	Figure 2
8	Co-occurance of all keywords	**	Figure 3
	Distribution of frequently used keywords by authors by year	***	Graph 5
9	Keywords- authors- references	***	Figure 4
10	Distribution of articles according to corresponding author countries	***	Table 5

* Analysis of data obtained from WosCC was done with Microsoft Excel program.
** Analysis of data was done with VosViewer 1.6.20 software.
*** Analysis of data was done with R 4.4.1 version, R studio, bibliometrix/ biblioshiny.

2.3.1. *Ensuring validity and reliability*

In scientific research, the factors that support validity are that the research serves its purpose, the findings reflect the truth, and the accuracy of the research results (Creswell & Clark, 2007). To increase the validity of this study, a search was conducted in WoSCC by creating a keyword group that would cover the subject of the study after receiving the opinions of three field experts. In addition, while searching in WoSCC, preferences (inclusion-exclusion) were made in accordance with the purpose of the study. When the keywords "science education" and "formative assessment" were used in WoSCC, 146 documents were accessed, when the keyword group related to physics, chemistry, biology and science education was used, 304 documents were accessed, and when the search was made within the article, 213 articles were accessed. To ensure/increase the reliability of the study, which is related to the reproducibility of the research results, the data collection process was explained in detail, and a screenshot of the search results made in WoSCC is included in Appendix.

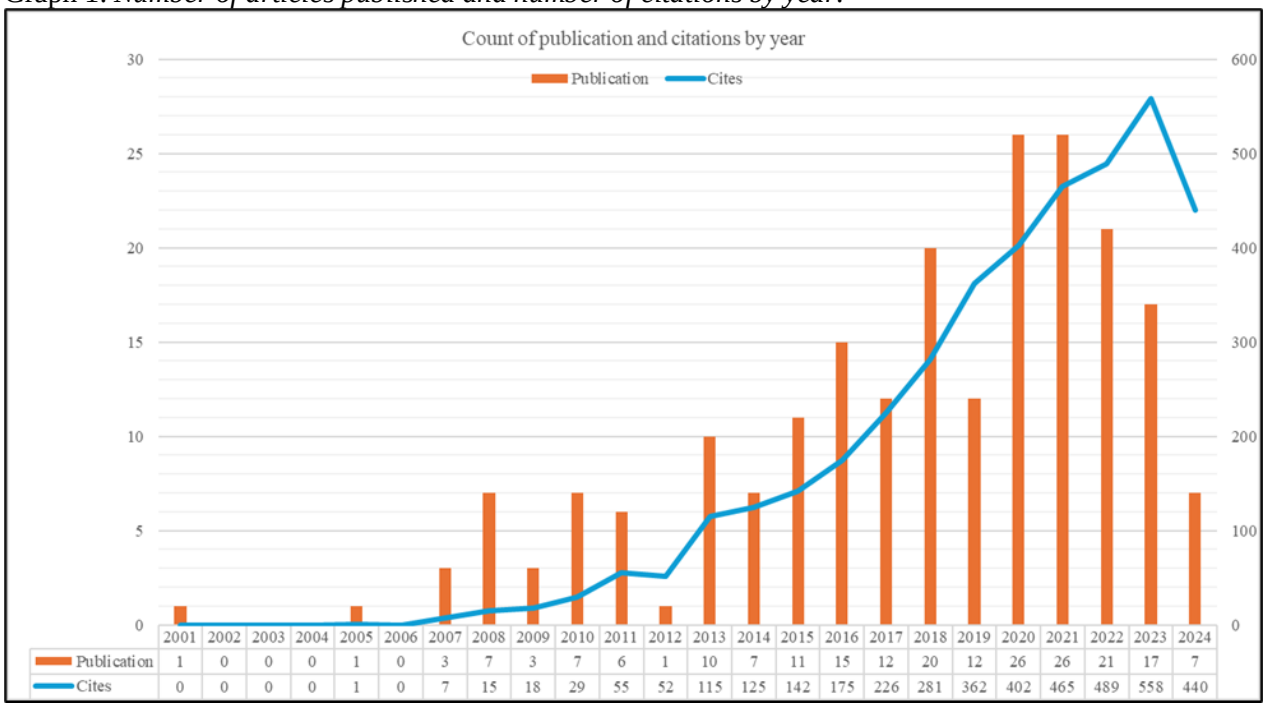
3. RESULTS / FINDINGS

In this section, the results of the data analysis are presented in the form of graphs, figures and tables to address the research topics.

3.1. Distribution of Published Articles by Year and Number of Citations

When a search is made in the Web of Science Core Collection under this title without limiting the publications by year, it is seen that the articles related to the subject started to be published since 2001. It is seen that the number of publications decreased after 2020-2021. It is seen that the number of citations of the articles decreased in 2023-2024 (Graph 1).

Graph 1. *Number of articles published and number of citations by year.*

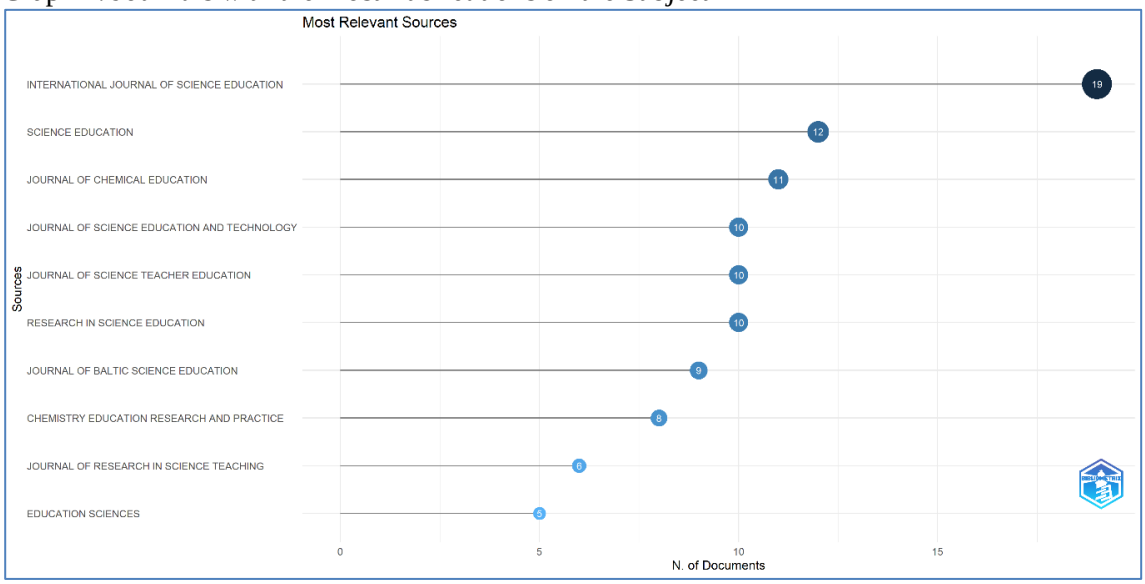


	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Publication	1	0	0	0	1	0	3	7	3	7	6	1	10	7	11	15	12	20	12	26	26	21	17	7
Cites	0	0	0	0	1	0	7	15	18	29	55	52	115	125	142	175	226	281	362	402	465	489	558	440

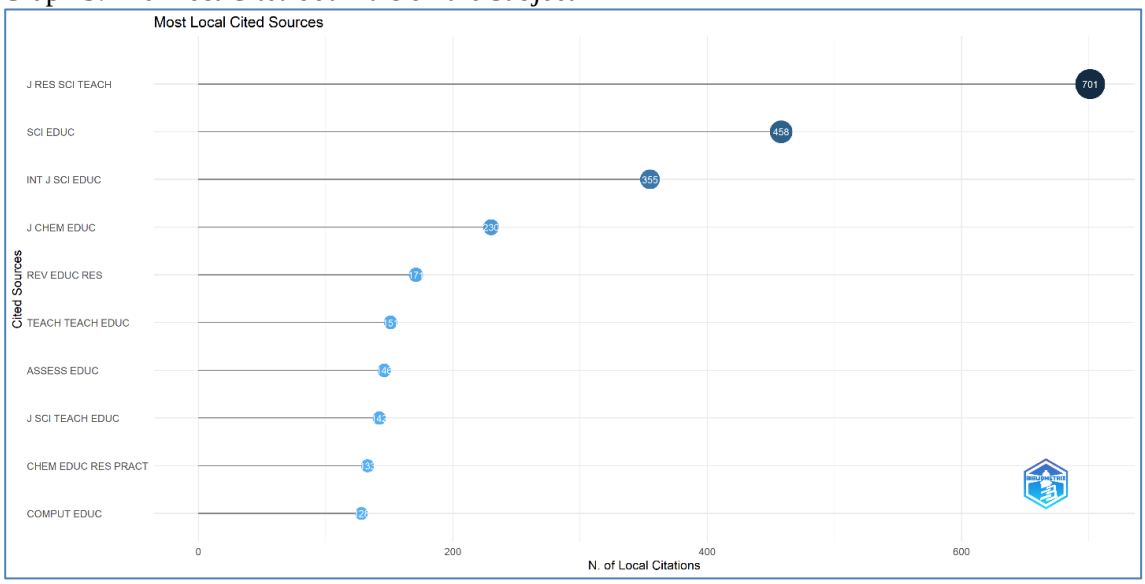
3.2. Journals with the Most Publications and Citations on the Subject

The ten journals that published the most articles on the subject (Graph 2) and the ten journals that received the most citations (Graph 3) are listed under this heading. It is seen that the journal that published the most articles (19) is “International Journal of Science Education”. It is seen that the journal with the most citations (701) is Journal of Research in Science Teaching

Graph 2. *Journals with the Most Publications on the Subject*



Graph 3. *The Most Cited Journals on the Subject*



In Graph 3, it was determined that the journal with the most citations (701) was "Journal of Research in Science Teaching", and the journals with the most publications (Graph 2) and the most citations (Graph 3) included "Science Education", "International Journal of Science Education", "Journal of Chemical Education", Journal of Research in Science Teaching", "Chemistry Education Research and Practice", and "Journal of Science Teacher Education".

3.3. Most Cited Articles

Information on the ten most cited articles on the subject is given in Table 3. When the most cited articles (Table 3) and the authors with the most articles (Graph 4) are examined together, it is seen that the authors of the most cited articles are not the authors who publish the most. However, it can be said that Furtak E.M. has made a great contribution to the literature in terms of both the number of articles and the number of citations to his articles. The contents of the most cited articles are briefly summarized below. Formative assessment activities should be prepared by experts in the field and the results obtained from the activities should be evaluated by experts in the field. These activities should enable students to use the information they learn in new situations they encounter (Wendy & Carl, 2010). The science concepts that the student has formed in his mind should be determined with formative assessment activities, the degree to which these concepts overlap with scientifically accepted concepts should be determined, and the teacher should provide feedback to the student accordingly.

Teacher-student dialogue is very important in this process (Bell & Cowie, 2001). The missing and incorrect information that the student has formed in his mind should be determined with formative assessment activities, and the reason for the student's missing or incorrect construction of the information should be examined. Teachers should be very sensitive in this process because students can sometimes express what they know correctly by using incomplete or incorrect words. Here, different question types can be used to determine the information that students' structure in their minds more clearly and as it is (Coffey et al., 2011). Laboratory practices in science education are effective learning environments that support students to internalize and structure information in their minds. Students working like scientists in laboratories, comparing their self-assessment rubrics with experimental results in the process of obtaining information, and exchanging ideas with course instructors about the experimental results can contribute to the student's learning environment (Etkina et al., 2010). In science education, it is especially important to integrate instant and interactive formative assessment activities into the curriculum through the joint work of program developers and formative assessment developers (Shavelson et al., 2008). In science education, in formative assessment activities, it is especially important for the teacher to encourage students to think and create a classroom discussion environment in the learning process of information and communication technologies as a catalyst (Webb, 2005).

Table 3. *Information on the Ten Most Cited Articles*

Number	Years	Article title	Authors	Journal Name	Total number of citations	Annual citation average
1	2010	Development and Validation of Instruments to Measure Learning of Expert-Like Thinking	Adams, Wendy K.; Wieman, Carl E.	International Journal of Scıence Educatıon	232	16,57
2	2001	The characteristics of formative assessment in science education	Bell, B; Cowie, B	Science Education	210	8,75
3	2011	The Missing Disciplinary Substance of Formative Assessment	Coffey, Janet E.; Hammer, David; Levin, Daniel M.; Grant, Terrance	Journal of Research in Science Teaching	197	14,07
4	2010	Design and Reflection Help Students Develop Scientific Abilities: Learning in Introductory Physics Laboratories	Etkina, Eugenia; Karelina, Anna; Ruibal-Villasenor, Maria; Rosengrant, David; Jordan, Rebecca; Hmelo-Silver, Cindy E.	Journal of the Learning Sciences	147	9,8
5	2008	On the Impact of Curriculum-Embedded Formative Assessment on Learning: A Collaboration between Curriculum and Assessment Developers	Shavelson, Richard J.; Young, Donald B.; Ayala, Carlos C.; Brandon, Paul R.; Furtak, Erin Marie; Ruiz-Primo, Maria Araceli; Tomita, Miki K.; Yin, Yue	Applied Measurement in Education	121	7,12
6	2005	Affordances of ICT in science learning: implications for an integrated pedagogy	Webb, ME	International Journal of Science Educatıon	107	5,35
7	2016	Effects of a computer-assisted formative assessment intervention based on multiple-tier diagnostic items and different feedback types	Maier, Uwe; Wolf, Nicole; Randler, Christoph	Computers & Education	89	9,89

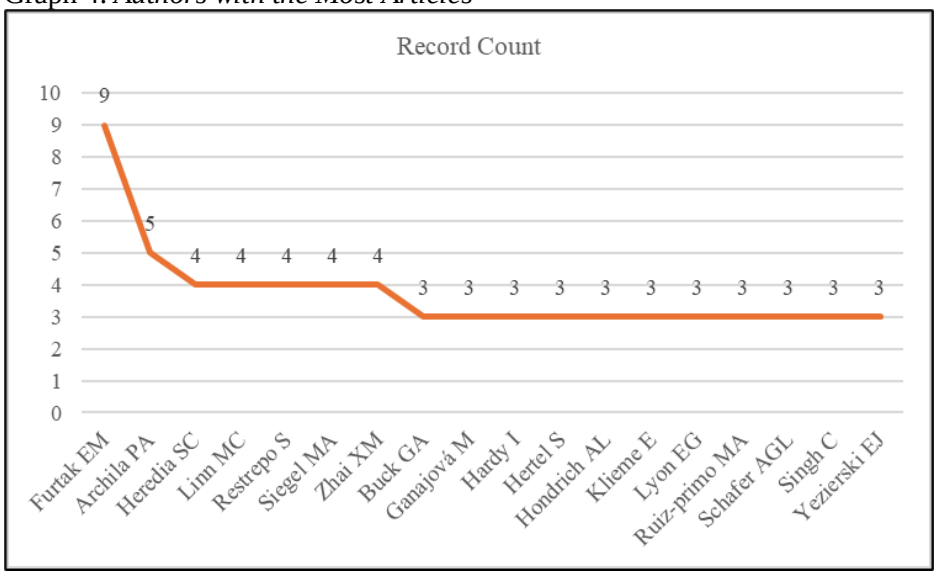
8	2016	Teachers' formative assessment abilities and their relationship to student learning: findings from a four-year intervention study	Furtak, Erin Marie; Kiemer, Katharina; Circi, Ruhan Kizil; Swanson, Rebecca; de Leon, Vanessa; Morrison, Deb; Heredia, Sara C.	Instructional Science	80	8,89
9	2020	The effect of automated feedback on revision behavior and learning gains in formative assessment of scientific argument writing	Zhu, Mengxiao; Liu, Ou Lydia; Lee, Hee-Sun	Computers & Education	76	15,2
10	2014	Epistemology and expectations survey about experimental physics: Development and initial results	Zwickl, Benjamin M.; Hirokawa, Takako; Finkelstein, Noah; Lewandowski, H. J.	Physical Review Special Topics-Physics Education Research	73	6,64

There are some limitations in the effective implementation of formative assessment activities, some of which are insufficient class hours, handling complex concepts (Maier et al., 2016), and inadequacy of science teachers in revealing the knowledge in students and providing appropriate feedback (Furtak et al., 2016). In determining the student's learning level in depth, computer-aided different types of feedback (descriptive, instant, simple, detailed, personalized) can contribute to the teaching process (Maier et al., 2016). In student success, it is very effective for teachers to design the formative assessment process well and to have the professional skills to reveal the thoughts of the students and provide feedback accordingly (Furtak, Kiemer, Circi, Swanson, Morrison & Heredia, 2016). Studies have shown that in formative assessment studies conducted with automatic feedback, multiple-choice exams are preferred more than exams with structured response items (Zhu et al., 2020). In addition to evaluating student learning in the teaching process, students who take laboratory courses can give educators an idea about what should be done to increase the efficiency of laboratory courses (Zwickl et al., 2014).

3.4. Authors with the Most Articles

This title includes researchers who have at least three articles on the subject (Graph 4).

Graph 4. *Authors with the Most Articles*



It is seen that Furtak EM is the author with the most articles on the subject (9 articles) (Graph 4).

3.5. Article Information Published from Turkey on the Subject

In this title, articles published from Turkey on the subject are included as a result of the search made in the WoSCC database (Table 4).

Table 4. *Information of Articles Published from Turkey*

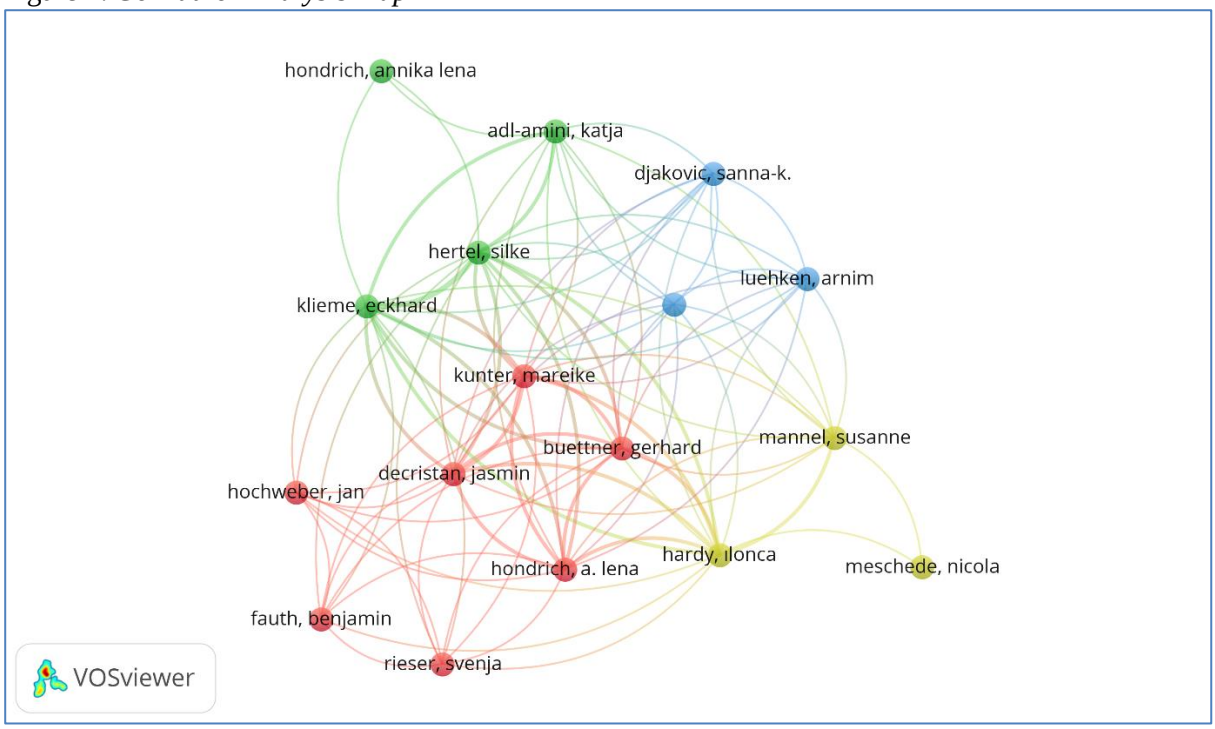
Year	Article title	Authors	Journal name	Institution	Total Number of Citations
2022	Formative assessment practices in science education: A meta-synthesis study	Atasoy, V; Kaya, G	Studies In Educational Evaluation	Kastamonu University	2
2019	Biology Teachers' Practices of Formative Assessment: A Case of the Identifying Learning Gap Element	Bayrak, N; Çalik, M; Dogan, S	Pamukkale University Journal of Education	Trabzon University; Erzincan Binali Yildirim University	2
2014	Effects of formative assessment probes integrated in extracurricular hands-on science: middle school students' understanding	Bulunuz, N; Bulunuz, M; Peker, H	Journal of Baltic Science Education	Uludag University; Ministry of National Education Turkey	7
2021	Does Teacher Education Matter? Comparison of Education and Science Major Teachers' Assessment Literacy	Demirdogen, B; Korkut, HM	Journal Of Qualitative Research in Education	Zonguldak Bulent Ecevit University; Marmara University	1
2022	The Effects of Formative Assessment Practices in Science Education on Students' Metacognitive Knowledge and Regulation Skills	Gedikli, H; Buldur, S	Hacettepe University Journal of Education	Cumhuriyet University	0
2021	The Role of Science Teachers' Awareness in their Classroom Practice of Formative Assessment	Kaya, G; Atasoy, V; Candan-Helvaci, S; Pektas, M	Egitim ve Bilim-Education and Science	Kastamonu University	3
2024	A Co-design Based Research Study: Developing Formative Assessment Practices with Preservice Science Teachers in a Chemistry Laboratory Setting	Kaya, ON; Kaya, Z	Research In Scıence Educatıon	Usak University	1
2023	Examining the type and quality of questions asked by a science teacher	Saka, T; Inaltekin, T	Journal Of Baltıc Scıence Educatıon	Kafkas University	2
2023	The Effect of Web-Based Biology Learning Environment on Academic Performance: A Meta-analysis Study	Vekli, GS; Çalik, M	Journal Of Scıence Educatıon and Technology	Bozok University; Trabzon University	3

The article titled “Effects of formative assessment probes integrated in extracurricular hands-on science: middle school students' understanding” published in 2014 appears to be the most cited article (Table 4).

3.6. Co-author analysis

To determine the co-authorship relationship of the authors, an analysis was conducted in the Vosviewer software with the criterion that an author has at least one publication. As a result of the analysis, 558 authors were included in the analysis (Figure 1).

Figure 1. *Co-Author Analysis Map*

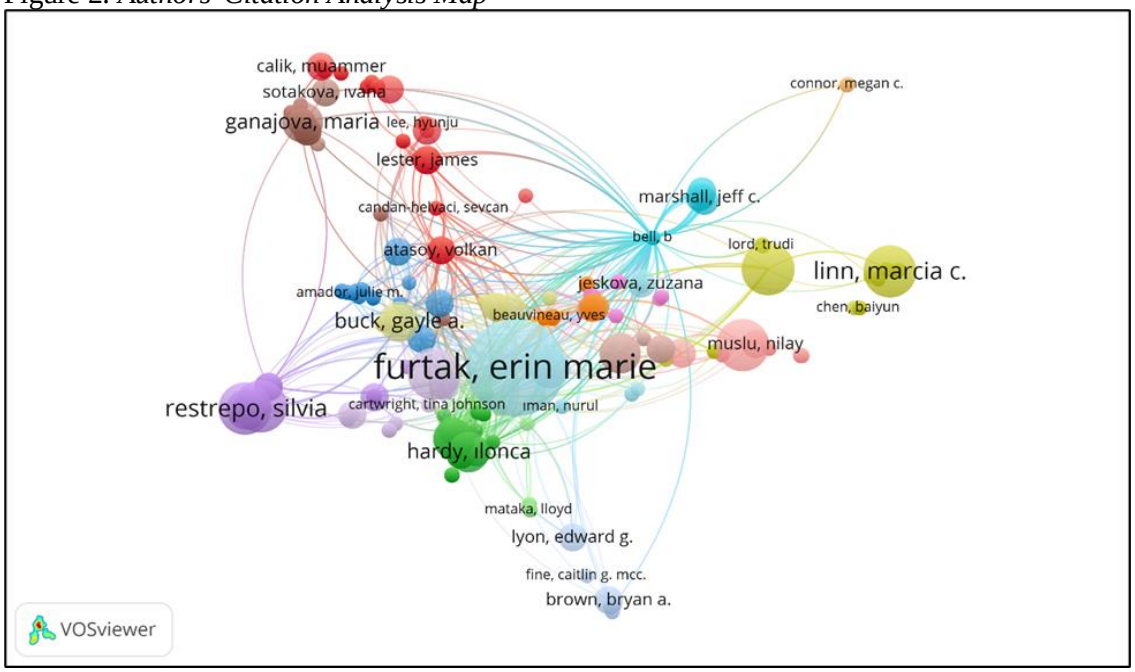


When Figure 1 is examined, it is seen that the 17 authors who are most connected to each other are in the main cluster. The main cluster is divided into four clusters (yellow, red, blue, green). In the analysis with 95 connections and a total connection power of 120, Hertel, S and Klieme, E are in the first place with 15 connections and a total connection power of 23. Hertel, S and Klieme, E are also seen to be among the researchers who have published the most with 3 articles. It was determined that Hardy, Ilonca is in second place with 15 connections and a total connection power of 22. Kunter, Mareike; Decristan, Jasmine; Hondrich, A. Lena; Buettner, Gerhard are in the third place with 14 connections and a total connection power of 20. It is seen that Hardy, I and Hondrich AL are also in the list of those who have published the most with 3 articles (Figure 1).

3.7. Authors' Citation Analysis

In the citation-author relationship analysis conducted with the Vosviewer program, it was determined that the number of authors was 558 and the number of authors receiving at least one citation was 515 (Figure 2). The analysis was conducted with the criteria of at least one publication and at least one citation for an author.

Figure 2. *Authors' Citation Analysis Map*

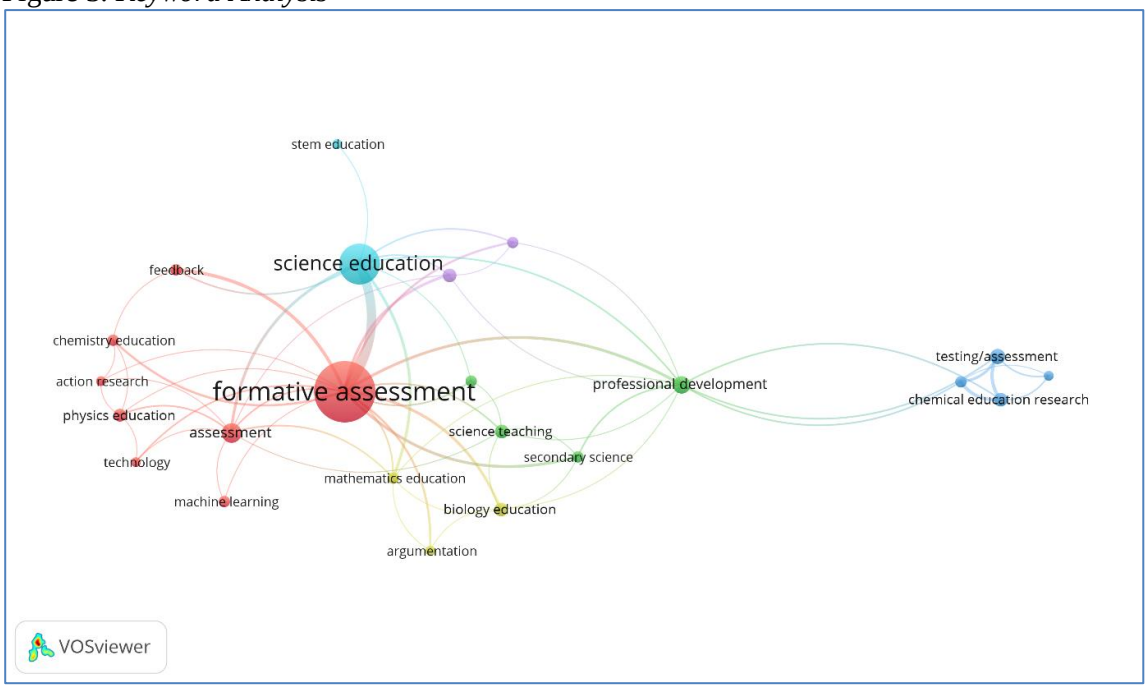


As a result of the citation analysis of the authors, the 338 authors with the most connections to each other were gathered in 17 clusters. It was determined that there were 2600 connections and a total connection strength of 3260. Furtak, who has 135 connections, and Erin Marie, who has a total connection strength of 257, are in first place. Bell, B, who has 132 connections and a total connection strength of 157, are in second place (Figure 2).

3.6. 8. Co-Occurence of All Keywords Analysis

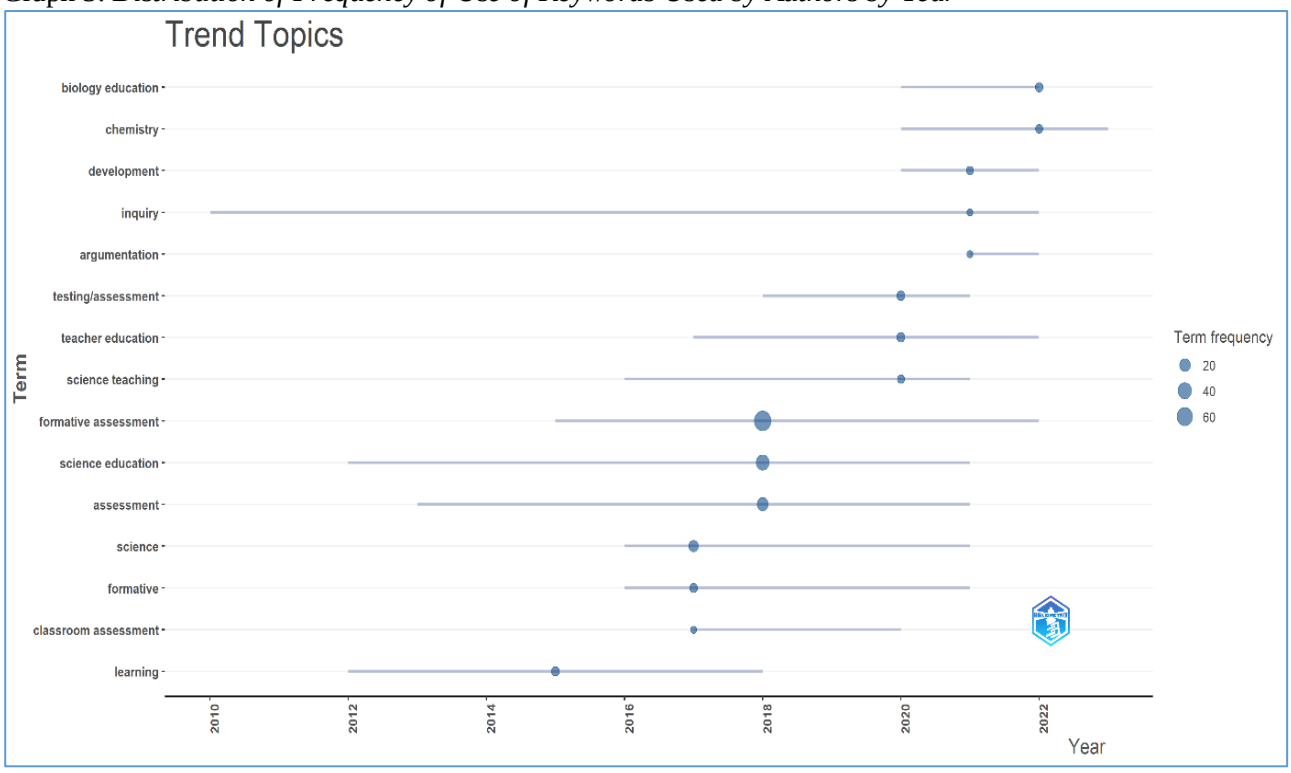
In the keyword analysis, when the analysis was made with the criterion that a keyword must be used at least four times, it was determined that 23 out of 551 keywords met this criterion (Figure 3). In addition, the result of the analysis made with Biblioshiny to see the distribution of keywords used by the authors by year is given in Figure 5.

Figure 3. *Keyword Analysis*



As a result of the analysis, it was determined that 23 keywords had 6 clusters, 60 connections and a total connection strength of 133. Among the 23 keywords, it was determined that "formative assessment" was repeated 79 times and had a total connection strength of 133. It was determined that "science education" was repeated 40 times and had a total connection strength of 36 and had 9 connections (Figure 3). It is seen that the authors frequently used the keywords "formative assessment" and "science education" in 2018, and the keywords "biology education" and "chemistry" were used in 2022 (Graph 5).

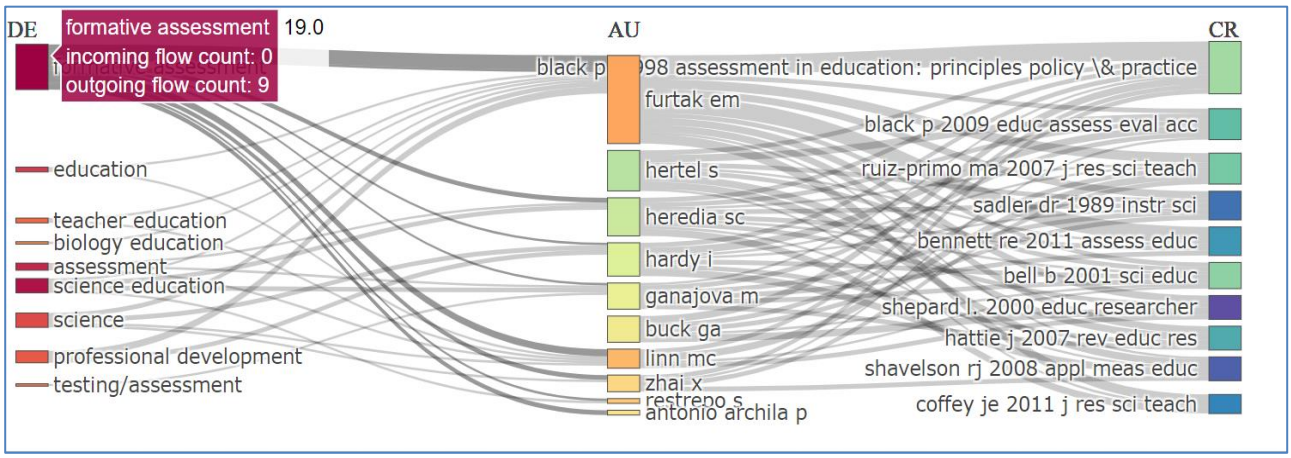
Graph 5. *Distribution of Frequency of Use of Keywords Used by Authors by Year*



3.6. 9. Keywords, Authors, References Analysis

The analysis of the three area graphs of keywords, authors and references in this title was created using the R program version 4.4.1, R studio, bibliometrix/ biblioshiny 4.1.2 package program. The analysis was conducted with a ten-keyword limitation in the right column, a ten-author limit in the middle column and a ten-reference limit in the left column (Figure 4).

Figure 4. *Three Area Plot Analysis of Relationships Between Keywords, Authors and References*



As seen in Figure 4, the most frequently used keyword at the end of the analysis is “formative assessment”, which is used by all authors except “Hertel S” and “Buck GA”. The keyword “science education” is used by “Furtak EM”, “Heredio SM”, “Ganajova M” and Restrepo S”. It is also seen that “Hertel S” and “Buck GA” authors do not use the keywords in the left column. In the right column, it is seen that the most frequently cited reference by the authors is “Black P. 1998 assessment in education: principles policy / & practice”.

3.6. 10. Distribution of Articles by Corresponding Author Country

In this title, the responsible authors are listed according to their countries. Here, the authors are analyzed according to whether they are from a single country or multiple countries (Table 5). The table was created with R studio.

Table 5. *Distribution of Articles by Corresponding Author Country*

Country	Number of articles	Article %	Single country articles	Multi country articles	Multi-country authors %
USA	103	48,4	97	6	5,8
CHINA	11	5,2	8	3	27,3
GERMANY	11	5,2	10	1	9,1
TURKEY	9	4,2	7	2	22,2
SPAIN	7	3,3	7	0	0
UNITED KINGDOM	7	3,3	7	0	0
SWEDEN	6	2,8	6	0	0
COLOMBIA	5	2,3	5	0	0
NETHERLANDS	5	2,3	4	1	20
AUSTRALIA	4	1,9	4	0	0

As seen in Table 5, most articles by single-country and multi-country authors are from the USA. It is also seen that Turkey ranks third on the list.

4. DISCUSSION and CONCLUSION

The search results from WoSCC, which are made within the framework of certain criteria, show that studies on the subject of formative assessment in science education have been published since 2001, and the number of publications increased in 2020-2021, which was the Covid 19 pandemic period. Content analysis of articles published between 2020-2021 can be performed, and it can be examined whether the articles published during these dates are related to “distance education” or “technology-supported education”. It can be seen that the most published and cited journals on the subject are journals in the field of science education such as International Journal of Science Education, Science Education, Journal of Research in Science Education, and; however, it can be seen that studies on the subject are also published and cited in the journals “Journal of science education and technology” and “computer education”, where technology-supported education studies are generally published. It can be said that as a result of the developments in information communication technology and the widespread use of these developments in the field of education, studies on formative assessment in science education will become widespread in technology-focused education journals.

It is seen that studies on the subject are published and cited in the teacher-focused journals “Teaching and Teacher Education” and “Journal of Science Teacher Education”. Also, It is seen that the most cited journal (Journal of Research in Science Teaching) is ranked ninth in the most published journals. It is seen that biology and physics education themed journals are not included in the list of journals related to chemistry education. It is seen that the most cited article on the subject is “Development and Validation of Instruments to Measure Learning of Expert-Like Thinking” published in 2011, and the second most cited article is “The characteristics of formative assessment in science education”. It is seen that the authors of the article ranked first in the citation

ranking Adams, Wendy. K & Wieman Carl. E and the authors of the article ranked second Bell, B & Cowie, B are not among the first 18 authors with the most publications on the subject. As can be seen from Graph 4, the authors who contributed to the literature with the most studies on the subject are Furtak EM (9 articles) and Archilla PA (5 articles). It is seen that the two articles that Furtak EM was among the authors of in 2008 and 2016 are among the ten most cited articles (Table 3).

The most cited articles can be summarized under ten headings according to their subject content. i- The importance of having formative assessment activities prepared by experts in the field and having the results evaluated by experts in the field, developing the student's ability to use the information he/she has learned, ii- Determining to what extent the concept that the student has formed in his/her mind matches the correct concept with formative assessment activities and providing appropriate feedback to the student, the importance of teacher-student communication in the feedback process, iii- Teachers need to be sensitive in determining whether the concepts that the student has constructed in his/her mind are correct, incorrect or incomplete with formative assessment activities. Students can sometimes express the concepts they have constructed correctly using the wrong words. Teacher-student communication is very important here. iv- In science laboratory applications, students can realize their deficiencies/mistakes and make arrangements as a result of their interviews with teachers using self-assessment rubrics while structuring their knowledge. v- It is very important to integrate formative assessment activities into the curriculum in science education, and for this, it is very important for program development experts and experts who prepare formative assessment activities in science education to cooperate. vi- Developments in information and communication technologies can act as a catalyst in formative assessment activities in science education, and here it is very important for the teacher to plan the classroom discussion environment. vii- Teacher competence is very important in carrying out formative assessment activities effectively in science education. viii- In depth determination of student level and provision of different types of feedback (descriptive, detailed etc.) to the student are very important in formative assessment activities in science education, and here again the teacher competence is very important. ix- Effective use of developments in information and communication technologies is very important. Especially in systems where automatic feedback is used, only multiple-choice question types should not be used. x- Students' evaluations of the course process can provide important clues about the arrangements that teachers should make in the teaching process. When these ten summarized topics are considered holistically, it is seen that there are teachers who are program implementers at the center.

With the advancements in information and communication technologies, access to technology has facilitated easier access to information, resulting in changes in the role of the teacher, which was traditionally viewed as a source of knowledge. Students now have easier access to information. However, in the field of science education, which some students perceive as an abstract accumulation of concepts, it can be said that the role of the teacher has become increasingly important in supporting students' ability to accurately structure their knowledge and to transform the knowledge they acquire into skills that can be applied in their daily lives. This is particularly significant in the formative assessment process, where the teacher provides feedback that enhances students' learning motivation.

Declaration of Conflicting Interests and Ethics

The authors declare no conflict of interest. This research study complies with research publishing ethics. The scientific and legal responsibility for manuscripts published in IJEDAI belongs to the author(s).

REFERENCES

Adams, W. K., & Wieman, C. E. (2010). Development and validation of ınstruments to measure learning of expert-like thinking. *International Journal of Science Education*, *33*(9), 1289–1312. https://doi.org/10.1080/09500693.2010.512369

Aria, M., & Cuccurullo, C. (2017). bibliometrix: An R-tool for comprehensive science mapping analysis. *Journal of Informetrics*, *11*(4), 959-975, http://dx.doi.org/10.1016/j.joi.2017.08.007

Atasoy, V., & Kaya, G. (2022). Formative assessment practices in science education: A meta-synthesis study. *Studies in Educational Evaluation*, *75*, 101186. https://doi.org/10.1016/j.stueduc.2022.101186

Atilgan, H., Kan, A., Dogan, N. (2009). Eğitimde Ölçme ve Değerlendirme; Ani Yayincilik: Ankara, Turkey.

Bayrak, N., Calik, M., & Doğan, S., (2019). Biology teachers' practices of formative assessment: a case of the ıdentifying learning gap element. *Pamukkale Unıversıtesı Egıtım Fakultesı Dergısı-Pamukkale Unıversıty Journal of Educatıon*, 132-149. https://doi.org/10.9779/pauefd.440455

Bennett, R. E. (2011). Formative assessment: A critical review. *Assessment, in Education Principles, Policy & Practice, 18*(1),5 25. https://doi.org/10.1080/0969594X.2010.513678

Bell, B., & Cowie, B. (2001). The characteristics of formative assessment in science education. *Science Education*, 85(5), 536-553. https://doi.org/10.1002/sce.1022

Bulunuz, M., & Bulunuz, N. (2013). Fen öğretiminde biçimlendirici değerlendirme ve etkili uygulama örneklerinin tanıtılması. *Journal of Turkish Science Education, 10*(4), 119-135. https://doi.org/10.36681/

Bulunuz, N., Bulunuz, M., & Peker, H. (2014). Effects of formative assessment probes integrated in extra-curricular hands-on science: Middle school students' understanding. *Journal of Baltic Science Education, 13*(2), 243. https://doi.org/10.33225/jbse/14.13.243.

Buchanan, T. (2000). The efficacy of a World-Wide Web mediated formative assessment. *Journal of Computer Assisted Learning*, 16(3), 193-200. http://dx.doi.org/10.1046/j.1365-2729.2000.00132.x

Bibliometrix. (2025, 9 July). https://www.bibliometrix.org/home/index.php/layout/bibliometrix

Coffey, J. E., Hammer, D., Levin, D. M., & Grant, T. (2011). The missing disciplinary substance of formative assessment. *Journal of Research in Science Teaching, 48*(10), 1109-1136, https://doi.org/10.1002/tea.20440

Cowie, B. & Beverley, B. (1999). A Model of formative assessment in science education, *Assessment in Education: Principles, Policy & Practice, 6*(1), 101-116, https://doi.org/10.1080/09695949993026

Demirdöğen, B., & Korkut, H. M. (2021). Does teacher education matter? Comparison of education and science major teachers' assessment literacy. *Eğitimde Nitel Araştırmalar Dergisi*, (26), 23-52. https://doi.org/10.14689/enad.26.2.

Dini, V., Sevian, H., Caushi, K., & Orduña Picón, R. (2020). Characterizing the formative assessmentenactment of experienced science teachers. *Science Education*, *104*(2), 290–325. https://doi.org/10.1002/sce.21559

Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., & Lim, W. M. (2021). How to conduct a bibliometric analysis: An overview and guidelines. *Journal of Business Research*, 133, 285–296. https://doi.org/10.1016/j.jbusres.2021.04.070

Etkina, E., Karelina, A., Ruibal-Villasenor, M., Rosengrant, D., Jordan, R., & Hmelo-Silver, C. E. (2010). Design and reflection help students develop scientific abilities: learning in ıntroductory physics laboratories. *Journal of the Learning Sciences, 19*(1), 54–98. https://doi.org/10.1080/10508400903452876

European University Institute. (2025, 9 July). https://www.eui.eu/Research/Library/ResearchGuides/Economics/WebofScience#:~:text=The%20We%20of%20Science%20is,for%20the%20Web%20of%20Science.

Furtak, E. M., Kiemer, K., Circi, R. K., Swanson, R., de León, V., Morrison, D., & Heredia, S. C. (2016). Teachers' formative assessment abilities and their relationship to student learning: Findings from a four-year intervention study. *Instructional Science*, 44(3), 267–291. https://doi.org/10.1007/s11251-016-9371-3

Gedikli, H., & Buldur, S. (2022). The effects of formative assessment practices in science education on students' metacognitive knowledge and regulation skills. *Hacettepe University Journal of Education*, *37*(4), 1393-1415. doi: 10.16986/HUJE.2022.454

Grob, R., Holmeier, M., & Labudde, P. (2017). Formative assessment to support students' competences in ınquiry-based science education. *Interdisciplinary Journal of Problem-Based Learning*, *11*(2). https://doi.org/10.7771/1541-5015.1673

Hatziapostolou, T., & Paraskakis, I. (2010). Enhancing the impact of formative feedback on student learning through an online feedback system. *Electronic Journal of E-learning*, *8*(2), 111-122.

Hsu, J. L., Chou, H. W., & Chang, H. H. (2011). EduMiner: Using text mining for automatic formative assessment. *Expert Systems with Applications*, 38(4), 3431-3439. https://doi.org/10.1016/j.eswa.2010.08.129

İnaltun, H., & Ateş, S. (2018). Fen Bilimleri eğitiminde biçimlendirici değerlendirme: Literatür taraması. *Gazi Üniversitesi Gazi Eğitim Fakültesi Dergisi*, *38*(2), 567-612. https://doi.org/10.17152/gefad.353975

Kamble, A., Gauba, R., Desai, S. ve Golhar, D. (2021). Learners' perception of the transition to instructor-led online learning environments: Facilitators and barriers during the COVID-19 pandemic.

International Review of Research in Open and Distributed Learning, *22*(1), 199-215. https://doi.org/10.19173/irrodl.v22i1.4971

Kang, H., & Anderson, C. W. (2015). Supporting preservice science teachers' ability to attend and respond to student thinking by design. *Science Education*, *99*(5), 863–895. https://doi.org/10.1002/sce.21182

Kaya, O.N., Kaya, Z. A Co-design Based Research Study: Developing Formative Assessment Practices with Preservice Science Teachers in a Chemistry Laboratory Setting. *Res Sci Educ 54*, 739–774 (2024). https://doi.org/10.1007/s11165-024-10162-9

Kaya, G., Atasoy, V., Candan-Helvacı, S., & Pektaş, M. (2021). The role of science teachers' awareness in their classroom practice of formative assessment. *Education & Science/Egitim ve Bilim*, *46*(205). http://dx.doi.org/10.15390/EB.2020.8934

Lawton, D., Vye, N., Bransford, J., Sanders, E., Richey, M., French, D., & Stephens, R. (2012). Online learning based on essential concepts and formative assessment. *Journal of Engineering Education*, *101*(2), 244-287. https://doi.org/10.1002/j.2168-9830.2012.tb00050.x

LeidenMatrics (2025 9 July). https://www.leidenmadtrics.nl/articles/vosviewer-goes-online-part-1

Levin, D., Hammer, D., & Coffey, J. (2009). Novice teachers' attention to student thinking. *Journal of Teacher Education*, *60*(2), 142–154. https://doi.org/10.1177/00224871083302

Maier, U., Wolf, N., & Randler, C. (2016). Effects of a computer-assisted formative assessment intervention based on multiple-tier diagnostic items and different feedback types. *Computers & Education*, 95, 85-98. https://doi.org/10.1016/j.compedu.2015.12.002

Menezes, C. C. N., & De Bortolli, R. (2016). Potential of gamification as assessment tool. *Creative Education*, 7, 561-566. http://dx.doi.org/10.4236/ce.2016.74058

Sadi-Yılmaz, S., & Yasar, M. D. (2023). Effects of Web 2.0 tools (kahoot, quizlet, google form example) on formative assessment in online chemistry courses. *Journal of Science Learning*, *6*(4), 442-456.

Saka, T., & Inaltekin, T. (2023). Examining the type and quality of questions asked by a science teacher. *Journal of Baltic Science Education*, *22*(1), 83-99. https://doi.org/10.33225/jbse/23.22.83

Shavelson, R. J., Young, D. B., Ayala, C. C., Brandon, P. R., Furtak, E. M., Ruiz-Primo, M. A., Tomita, M.K., Yin, Y. (2008). On the ımpact of curriculum-embedded formative assessment on learning: a collaboration between curriculum and assessment developers. *Applied Measurement in Education*, 21(4), 295–314, https://doi.org/10.1080/08957340802347647

Terwase, T. N., & Oluwatoyin, C. (2018). Diagnostic assessment: A tool for quality control in education. *Journal of Educational Research and Review, 1*(1), 17-24.

Vekli, G. S., & Çalik, M. (2023). The effect of web-based biology learning environment on academic performance: a meta-analysis study. *Journal of Science Education and Technology*, *32*(3), 365-378. https://doi.org/10.1007/s10956-023-10033-4

Vosviewer (2025, 9 July). https://www.vosviewer.com/features/highlights#visualization

Webb, M. E. (2005). Affordances of ICT in science learning: implications for an integrated pedagogy. *International Journal of Science Education*, *27*(6), 705–735. https://doi.org/10.1080/09500690500038520

Zan, B. U. (2019). Doğrudan atıf, ortak atıf ve bibliyografik eşleşme yaklaşımlarına dayalı olarak araştırma alanlarının değerlendirilmesi. *Sosyal Bilimler Araştırmaları Dergisi*, *14*(2), 501-516.

Eugenia Etkina, Anna Karelina, Maria Ruibal-Villasenor, David Rosengrant, Rebecca Jordan & Cindy E. Hmelo-Silver (2010) Design and reflection help students develop scientific abilities: learning in ıntroductory physics laboratories, *The Journal of the Learnıng Scıences*, *19*(1), 54-98, DOI: 10.1080/10508400903452876

Zhu, M., Liu, O. L., & Lee, H. S. (2020). The effect of automated feedback on revision behavior and learning gains in formative assessment of scientific argument writing. *Computers & Education*, *143*, https://doi.org/10.1016/j.compedu.2019.103668

Zwickl, B. M., Hirokawa, T., Finkelstein, N., & Lewandowski, H. J. (2014). Epistemology and expectations survey about experimental physics: Development and initial results. *Physical Review Special Topics-Physics Education Research*, *10*(1), 010120. https://doi.org/10.1103/PhysRevSTPER.10.010120

APPENDIX

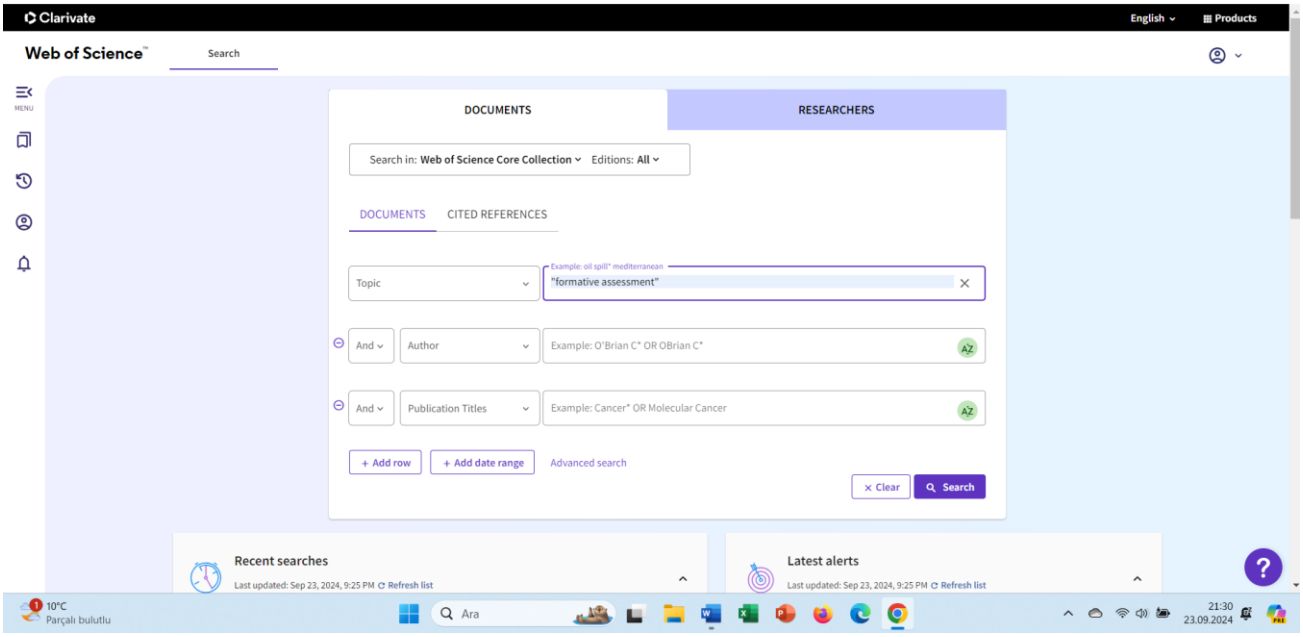


Figure1. *Web of Science Core Collection'dan "formative assessment" screenshot of the search with keywords*

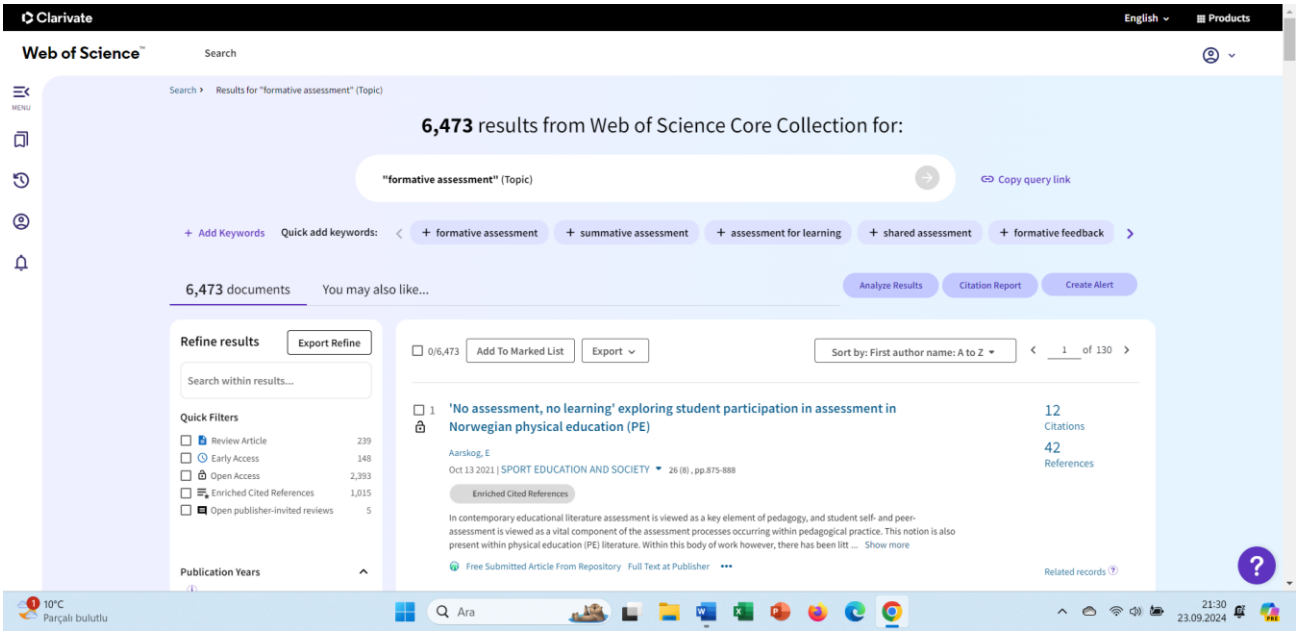


Figure 2. *Web of Science Core Collection'dan "formative assessment" screenshot of search results using keywords*

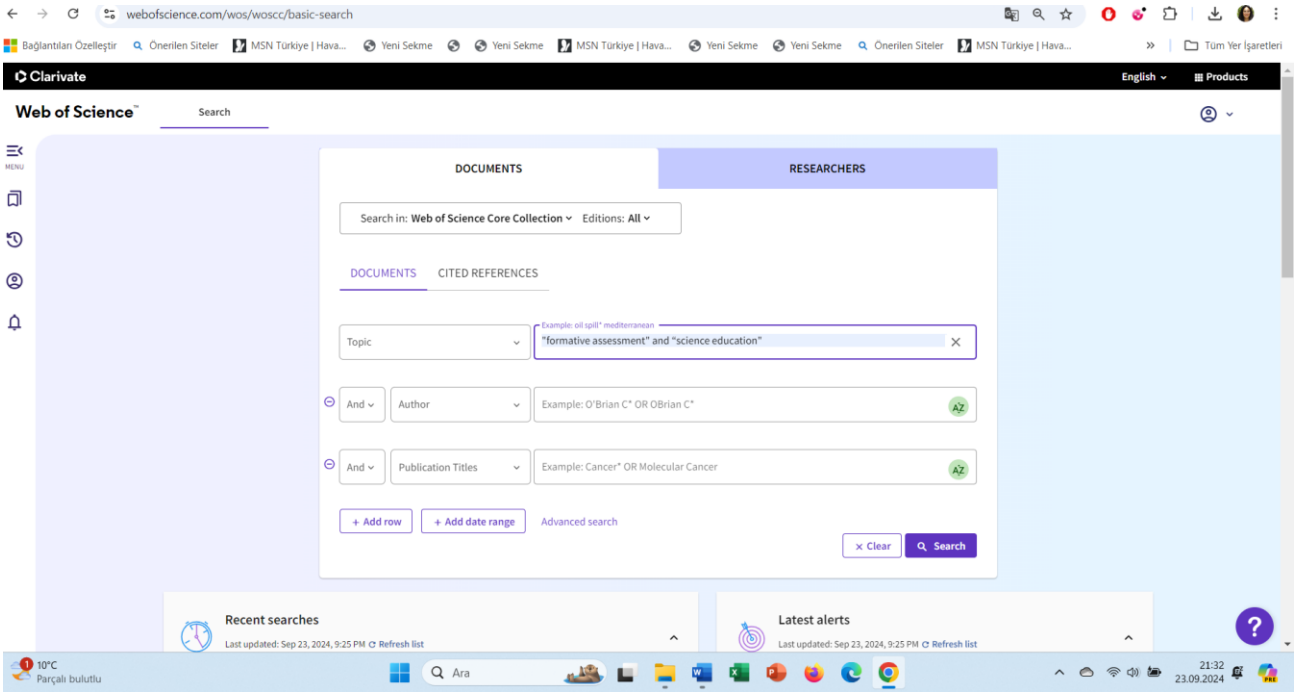


Figure 3. *Web of Science Core Collection'dan "formative assessment" and "science education" screenshot of search results using keywords*

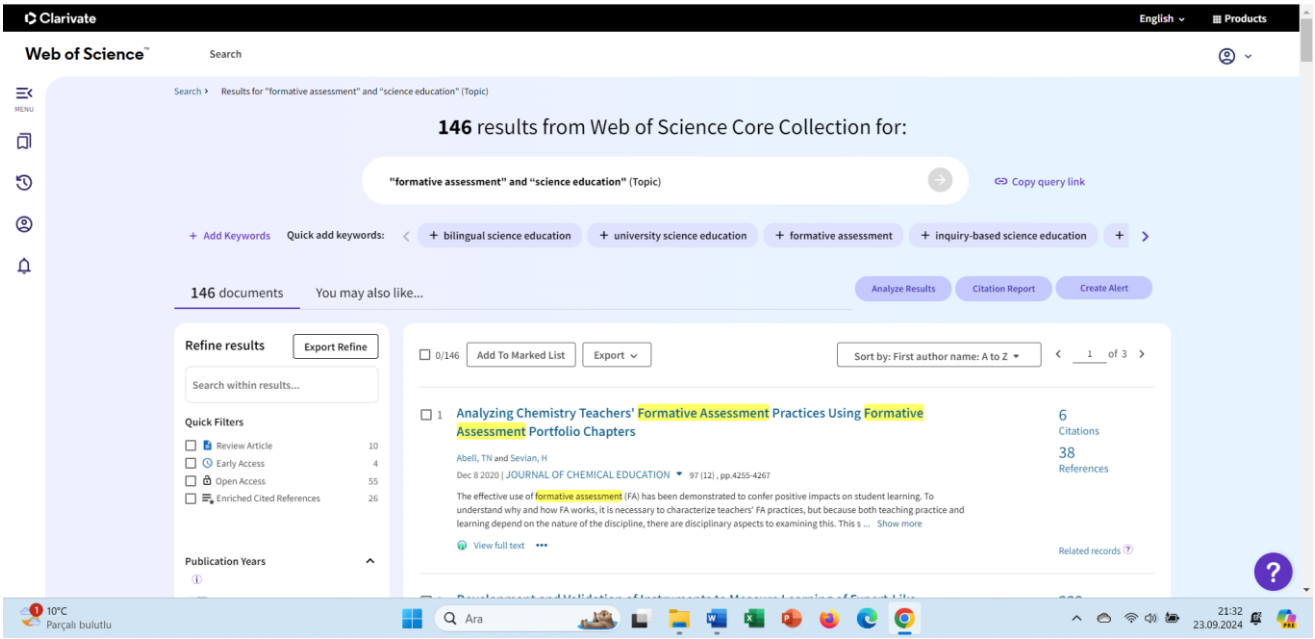


Figure 4. *Web of Science Core Collection'dan "formative assessment" and "science education" screenshot of search results using keywords*

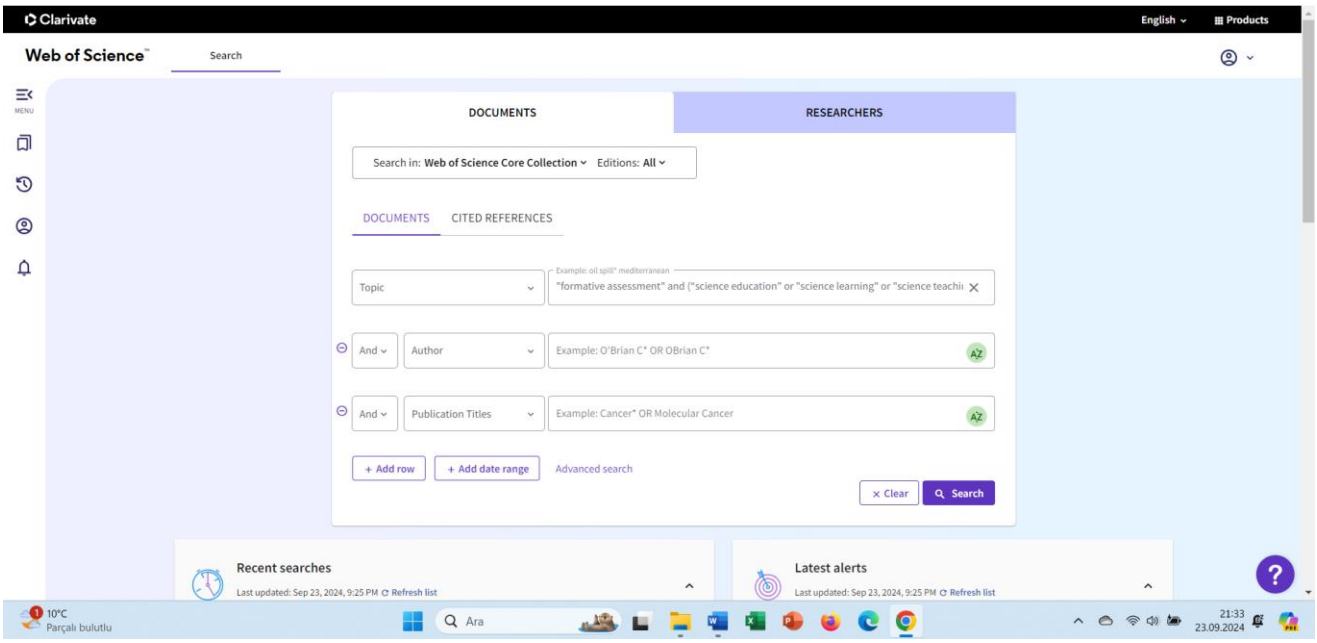


Figure 5. Web of Science Core Collection'dan *"formative assessment" and ("science education" or "science learning" or "science teaching" or "science teacher" or "science student" or "biology education" or "biology learning" or "biology teaching" or "biology teacher" or "chemistry education" or "chemistry learning" or "chemistry teaching" or "chemistry teacher" or "physics education" or "physics learning" or "physics teaching" or "physics teacher" or "science curriculum" or "biology curriculum" or " chemistry curriculum" or " physics curriculum"* screenshot of search results using keywords

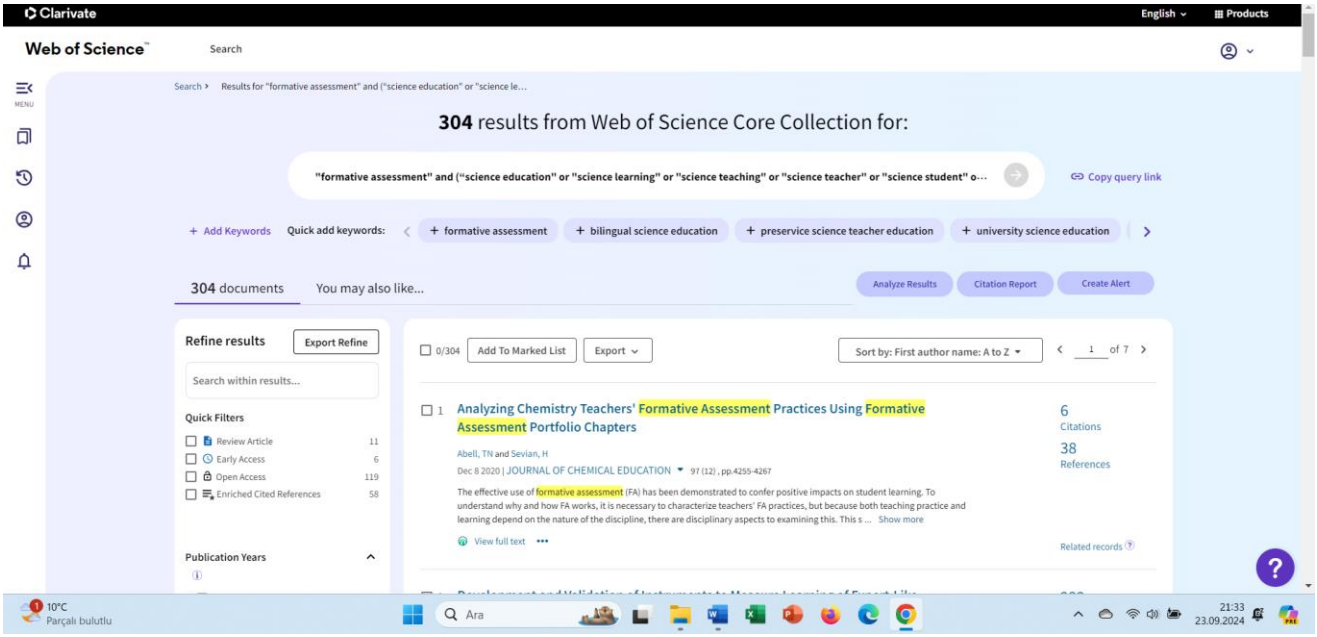


Figure 6. *Web of Science Core Collection'dan "formative assessment" and ("science education" or "science learning" or "science teaching" or "science teacher" or "science student" or "biology education" or "biology learning" or "biology teaching" or "biology teacher" or "chemistry education" or "chemistry learning" or "chemistry teaching" or "chemistry teacher" or "physics education" or "physics learning" or "physics teaching" or "physics teacher" or "science curriculum" or "biology curriculum" or " chemistry curriculum" or " physics curriculum" screenshot of search results using keywords*

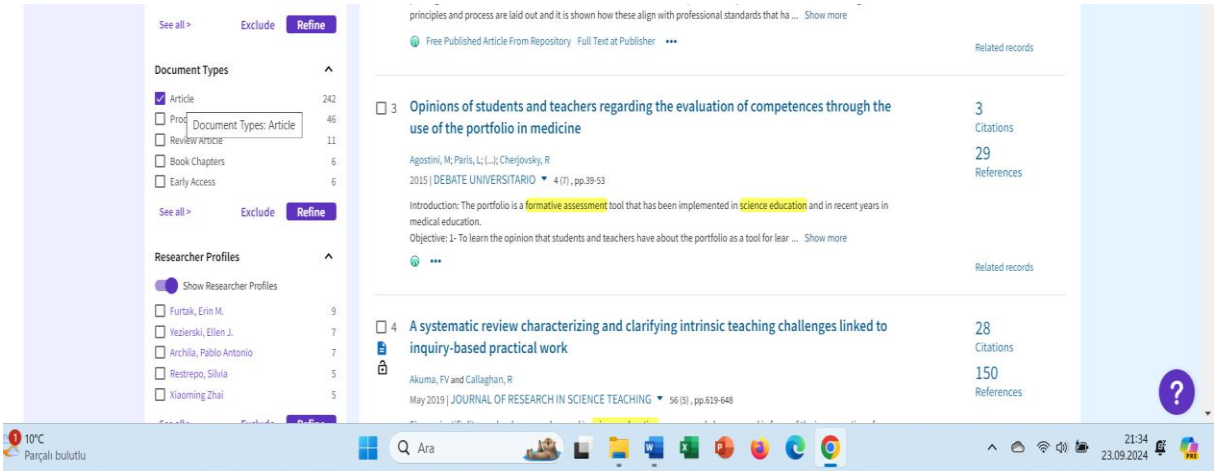


Figure 7. *Screenshot of the search where Document type is selected as article in the search*

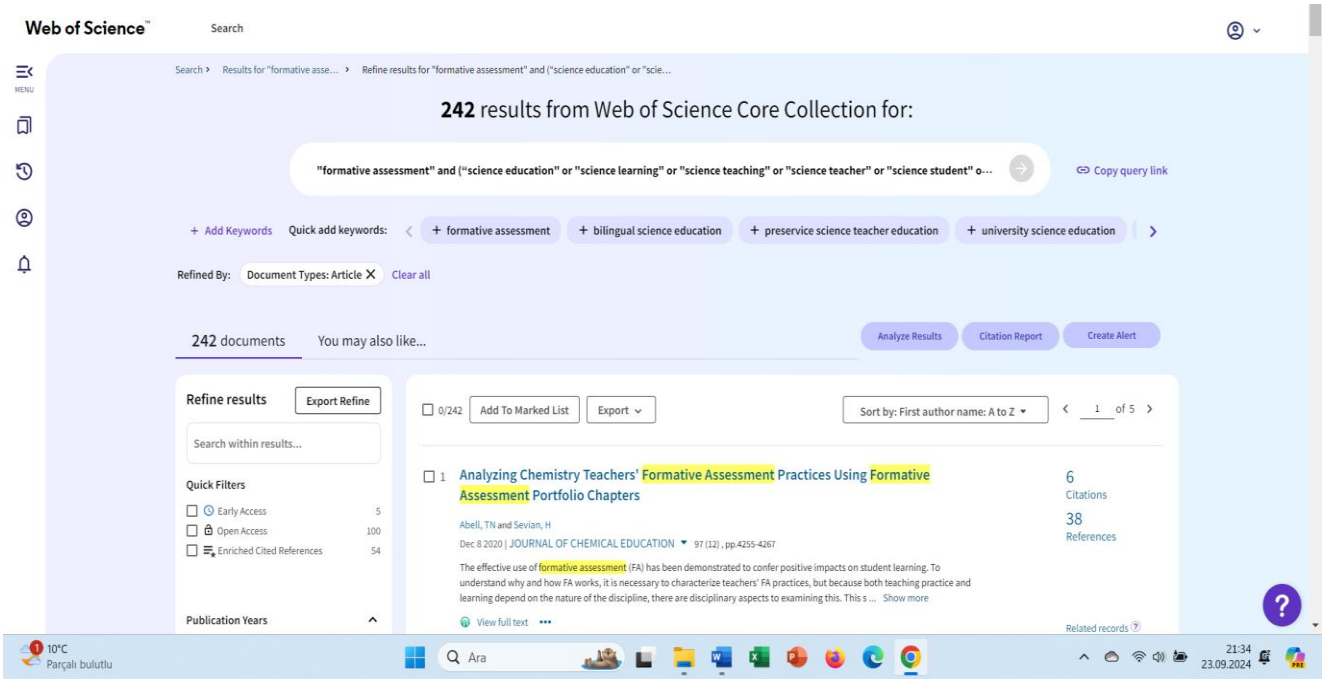


Figure 8. *Screenshot of the search result where the Document type is selected as article in the search*

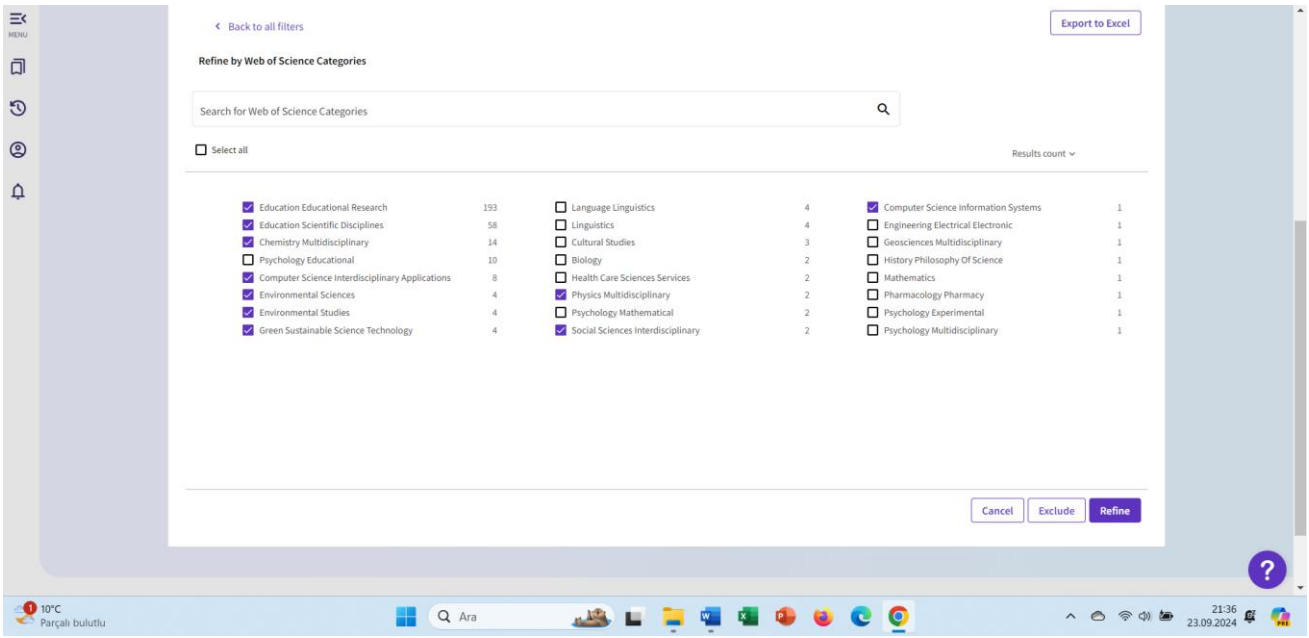


Figure 9. *"Web of Science Categories" preferred search options screenshot*

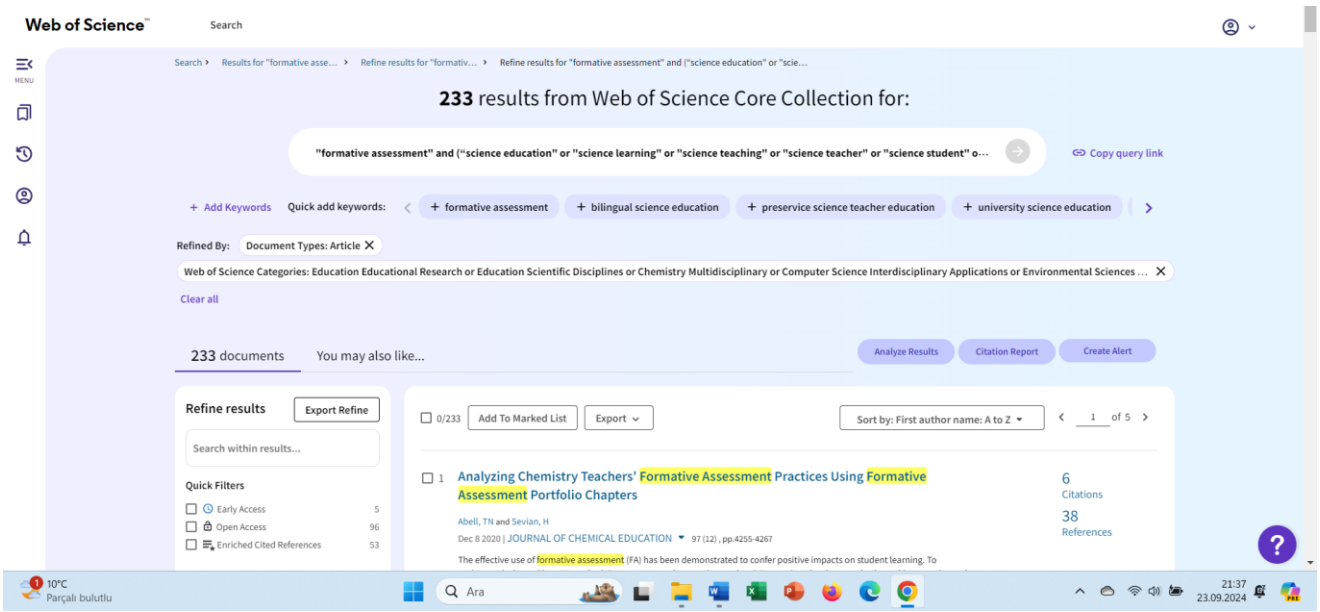


Figure 10. *"Web of Science Categories" screenshot showing the result of the chosen options*

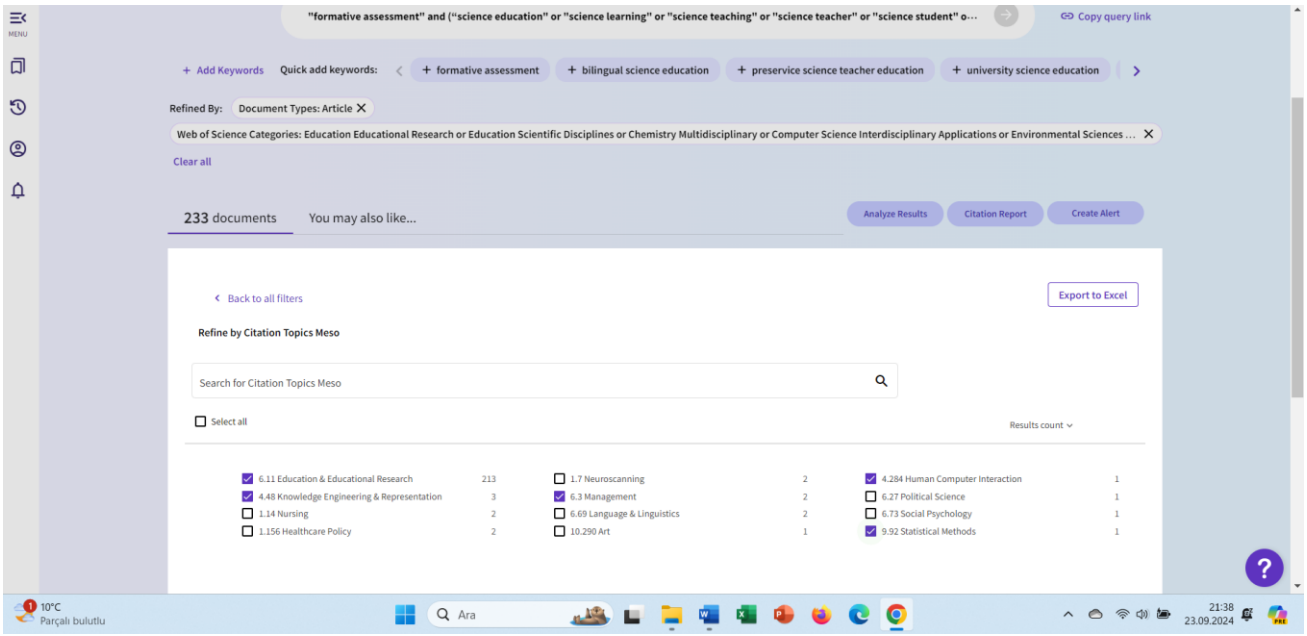


Figure 11. *"Refine by Citation Topics Meso" screenshot showing preferred search options result*

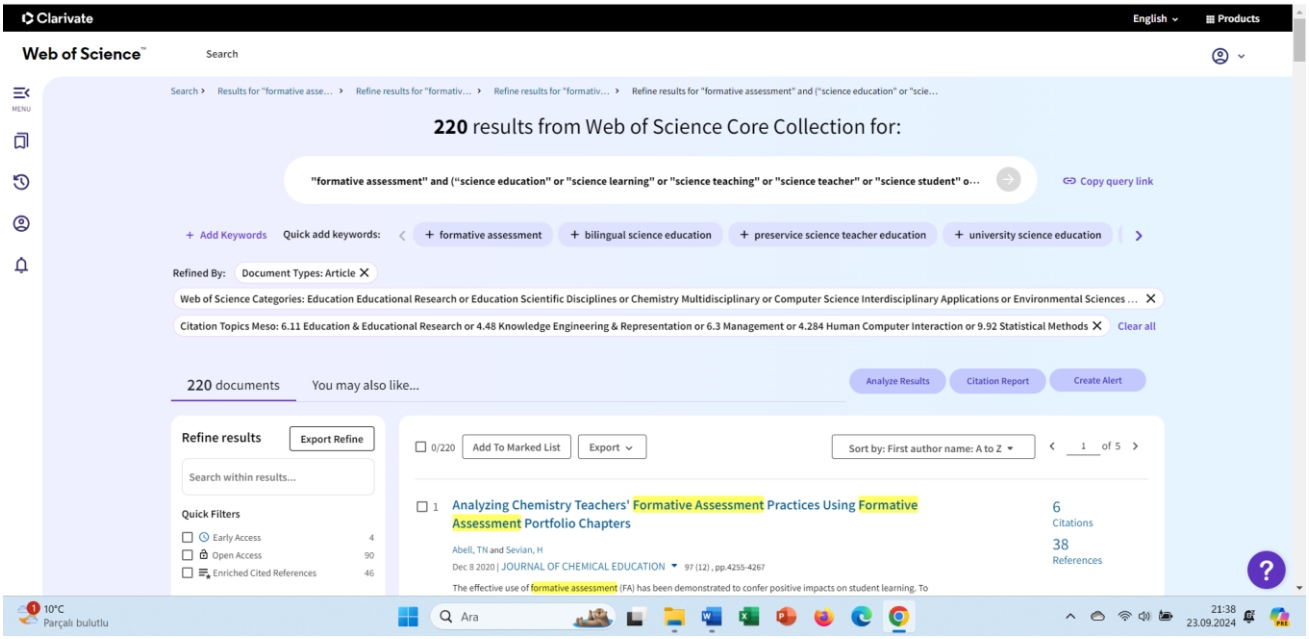


Figure 12. *"Refine by Citation Topics Meso" screenshot showing preferred search options result*

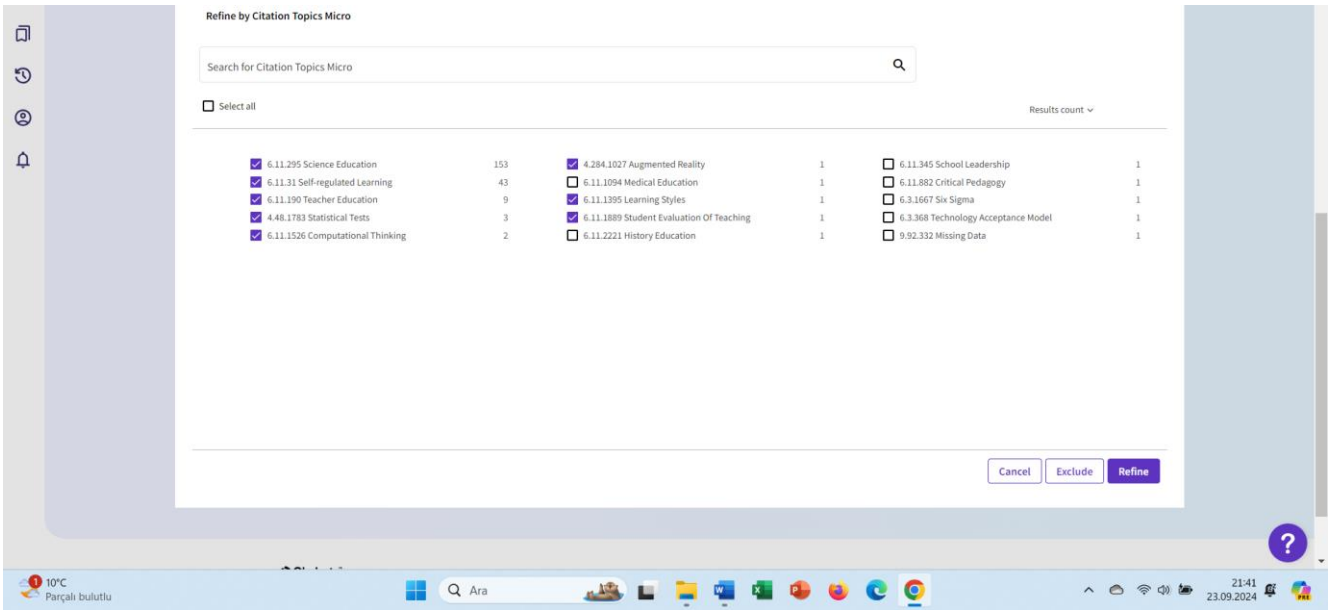


Figure *"Refine by Citation Topics Micro" screenshot showing preferred search options result*

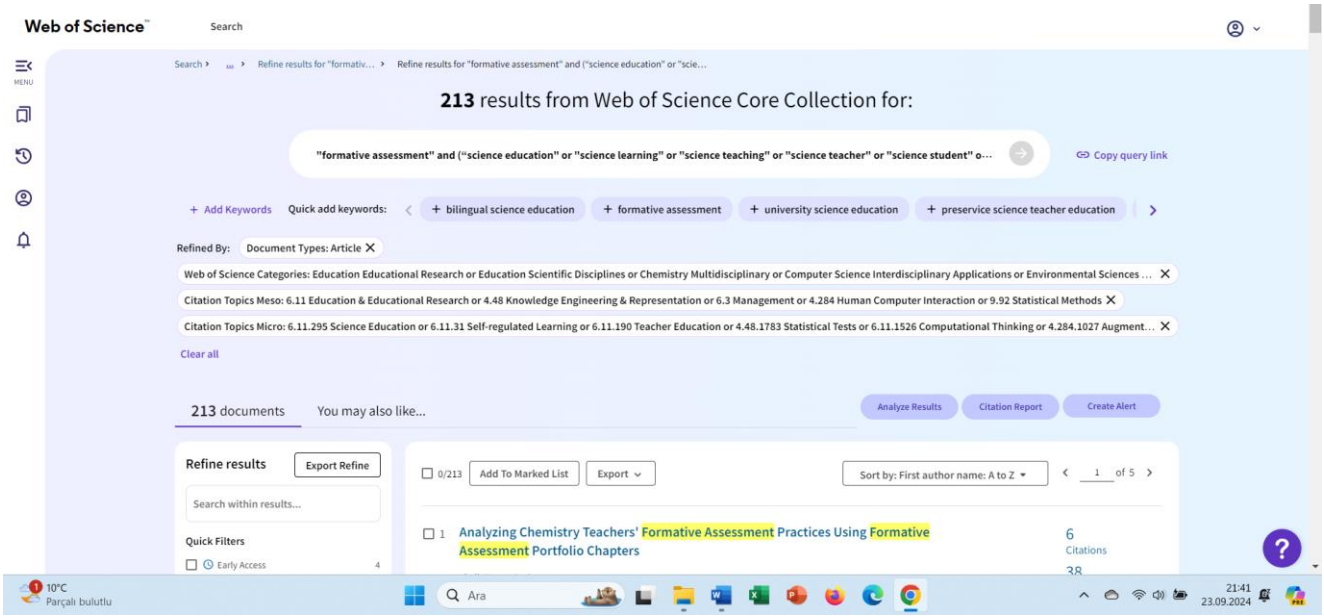


Figure 14. *"Refines by Citation Topics Micro" screenshot showing preferred search options result*

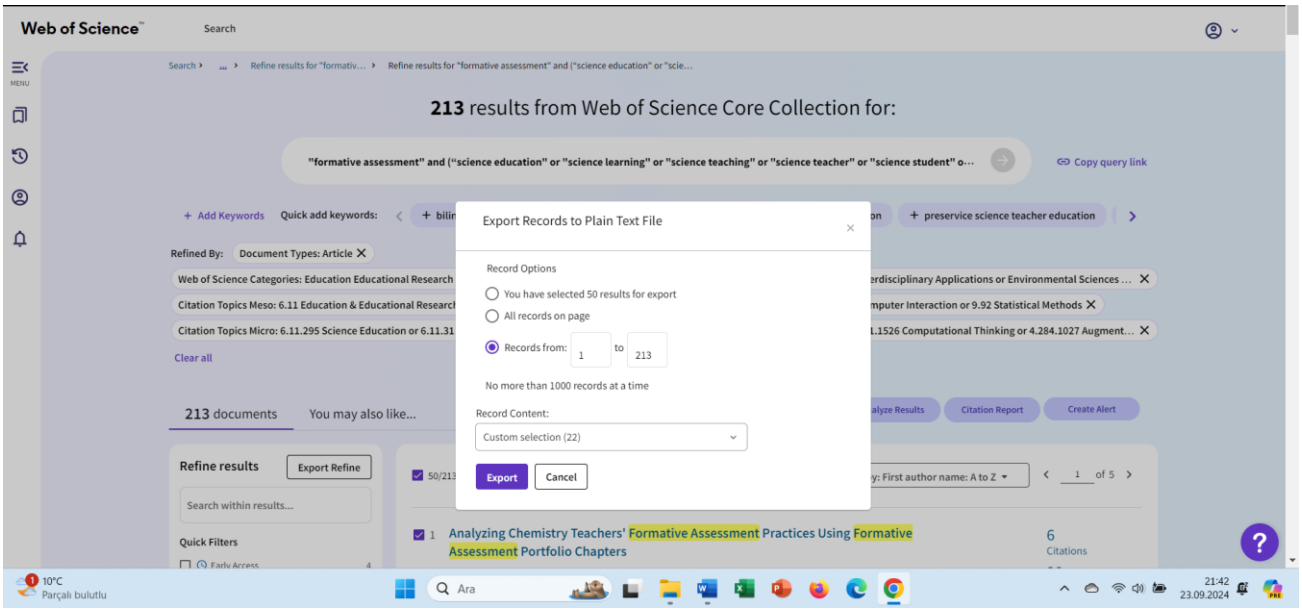


Figure 15. *Screenshot of the resulting data being saved*

Research Article https://doi.org/10.5281/zenodo.16620381

International Journal of Educational and Artificial Intelligence

Year 2025, Volume 2, Issue 1, page 41-55

ISSN: 3062-228X
http://www.ijedai.com/

Academics' views on problems and solution in biology education in 21st century Türkiye

Emine Kuru Kaçmazoğlu [1*], Nesrin Özmen [2]

[1] Department of Mathematics and Science Education, Faculty of Education, İnönü University, Türkiye

[2] Department of Mathematics and Science Education, Faculty of Education, İnönü University, Türkiye

Article Info

Submitted: 30.06.2025
Accepted: 24.07.2025
Published Online: 30.07.2025

Keywords

Biology education
Biology curriculum
Biology in the 21st century
Academician views

*Corresponding Author:

Emine Kuru Kaçmazoğlu

E-mail:
emine.kacmazoglu@inonu.edu.tr

Abstract

Purpose: Biology is a comprehensive discipline that studies the patterns, processes and interactions of all living things, including humans. Biology plays a pivotal role in interdisciplinary collaboration, and in addressing pressing problems on an individual, social, and global scale. The purpose of this study is to determine the views of academics' teaching undergraduate biology regarding biology education, its content, its problems, and solutions to these problems in Türkiye in the twenty-first century

Design and Methodology: In the study, phenomenological research design, one of the qualitative research methods, was used. The study was conducted with the participation of 24 academicians (13 female, 11 male) working in 14 different universities in Türkiye. The data were collected through a semi-structured form consisting of 5 demographic and 8 open-ended questions developed by the researchers. The analysis of the collected data was carried out by subjecting the participant responses to content analysis by creating themes and sub-themes.

Results: As a result of the research, the participants stated that biology is a basic science in the education of the 21st century youth, that it has an important place in recognizing nature, the universe and society and in solving current problems, and that biology education in Türkiye does not have sufficient quality and standards. Among the most fundamental problems encountered in biology education, the insufficiency of laboratory practices, the opening of biology departments that produce more graduates than needed and the decrease in course quality due to the lack of specialized academicians in these departments were pointed out.

Implications & Suggestions: Participants stated that National Science Education Standards and a curriculum aligned with contemporary content should be developed, and biology should be integrated with physics, chemistry, mathematics, and computer science. They also recommended that students actively participate in application-oriented projects during their undergraduate education.

To cite this article:

Kuru Kaçmazoğlu, E., & Özmen, N. (2025). Academics' views on problems and solution in biology education in 21st century Türkiye. *International Journal of Educational and Artificial Intelligence*, *2*(1), 41-55. https://doi.org/10.5281/zenodo.16620381

1. INTRODUCTION

Biology (Life sciences), which has an enormous interconnected field of study ranging from a single molecule to organism, ecosystem, and the biosphere that includes all living things on earth, is a very comprehensive discipline that studies the patterns, processes, and interactions of all living things, including humans (National Research Council [NRC], 2009; Quinn et al., 2012). The human species (Homo sapiens sapiens) is both a biological being, as a natural part of the biosphere, and a social being, as part of sociocultural evolution, which has caused major changes in the physical, chemical and biological structure of the Earth. Thanks to technology and, since the 17th century (considered the beginning of modern science), the scientific knowledge systematically accumulated through observation of nature, humans have been able to partially control nature and natural processes, increase their well-being, and achieve economic development. Technology and science closely influence and guide both the biological and social lives of humanity (NRC, 2009).

Some theoretical explanations, discoveries, and technological developments have been critical turning points that have carried science and society in new directions (Brooks, 1994). Until the first half of the 20th century, developments in physics and chemistry (for example, the discovery of the electron) were considered "hard" disciplines because they were the driving force of fundamental applications, new technologies, and economies that enabled social transformation, while biology, one of the most comprehensive disciplines of the natural sciences, was generally perceived as a verbal (a discipline dominated by theoretical explanations) or a "soft" science (Moore, 2007; NRC, 2009, p.39-40). The discovery of the molecular structure of DNA, which governs heredity, in 1953, and the discovery of recombinant DNA technology in the 1970s, revolutionized biology, which had previously focused on macroscopic phenomena, leading to more in-depth and molecular-level investigations on ‘how life works’ (Khan et al., 2016; NRC, 2003 (p.1 and 10-11); Öztürk, 2002). The integration of biological research and "-omics" technologies with new concepts and methods from multiple disciplines such as mathematics, physics, chemistry, computer science, and engineering has led to a tremendous accumulation of knowledge and transformation in the life sciences. This collaboration, particularly through the combination of bioinformatics, information technologies, and the powerful search engines of the internet, has provided access to an enormous amount of information (Misra et al., 2018; Robeva, et al., 2020; Yamin, 2019). This has led to the discovery of increasingly sophisticated ways to compare, predict, and manipulate fundamental commonalities and properties of life sciences, making life science resources accessible for a wide variety of applications (NRC, 2009 p. 13). This rapid flow of information offers enormous promise for addressing environmental, societal, and economic challenges facing humanity, such as improving health, enhancing food resources, and resilience to diverse environmental conditions (Bialek & Botstein, 2004; Khan et al., 2016; Kim, & Diong, 2012; Moore, 2007; Labov et al., 2010; NRC, 2009; Öztürk, 2002; Steitz, 2003).

In today's world, the integration and interaction between biology and computer science has led to the development of new fields and technologies such as bioinformatics, biorobotics, and artificial intelligence. It has enabled the storage, processing, and analysis of large amounts of data, such as gene sequencing and synthetic genomes, and the derivation of new information from them. Today, life sciences are considered a 'hard' discipline, where biology is increasingly transforming into technology (e.g., biorobotics), and technology into biology (e.g., artificial intelligence) (Boodhoo, 2024; Lartigue et al., 2007; Tamborini, 2024).

Biology is now at the point of being able to exploit these fundamental features of the living world and this ability has implications in many sectors. As a result of all these developments, the life sciences today have become a complex, multidisciplinary field with implications for both research and education, often directly affecting daily personal, social and political decisions (Klymkowsky et al., 2003; NRC, 2009). Today, life sciences are considered a 'hard' discipline, where biology is increasingly transforming into technology (e.g., biorobotics), and technology into biology (e.g., artificial intelligence) (Boodhoo, 2024; Lartigue et al., 2007; Tamborini, 2024).

On the other hand, this issue becomes even more salient when we consider the risks and problems it poses, such as information overload, an epidemic of misinformation (infodemic), the potential use of information as a biological weapon, the failure to protect personal data, and ethical issues (Scheufele, & Krause, 2019; Shahrzadi et al., 2024). Therefore, the importance of contemporary biology education has become increasingly important both for undergraduate biology students and for those who will inevitably become consumers of modern life sciences in the future (NRC, 2009).

The aim of this study is to determine the opinions of academics working in undergraduate life sciences programs regarding biology education in twenty-first-century Türkiye, its content, its problems, and the solutions to these problems, and to create a roadmap based on these opinions. To this end, the following questions will be answered:

1. What are academics' opinions on the role of biology and biology education in the education of 21st-century youth?

2. Do academics believe that biology education in Türkiye is of sufficient quality and standards?

3. What are academics' thoughts on the scope of the Biology Program that will meet 21st-century needs?

4. What are academics' thoughts on the fundamental problems in 21st-century biology education?

5. What can be done to improve the quality of biology education in Türkiye, solve its problems, and ensure that it is a priority for academics in career choices?

2. METHOD

2.1. Research Model

This study was conducted using the phenomenological design, a qualitative research method. Phenomenological studies are methods in which individuals or groups who have experienced and can externalize a specific phenomenon form the data source. Phenomenology, a process of inquiry that examines participants' experiences in depth, involves interactive investigation to develop patterns of meaning and relationships related to the phenomenon under investigation (Creswell, 2009; Patton, 2014). Their opinions were sought because academics working in undergraduate biology education, through their research and teaching roles, are the most experienced group capable of best reflecting the importance, problems, and proposed solutions to the life sciences, which constitute the scientific, technological, and economic driving force of the 21st-century world.

2.2. Sample of the Study

Participants comprised 24 lecturers/academics (13 women and 11 men) working at 14 different universities in Türkiye and holding various academic titles. Participants were selected using the criterion sampling technique, a purposive sampling method (Patton, 2014). The criterion for selecting participants was that they were employed in an undergraduate Life Science program. Participants' demographic characteristics are presented in Table 1.

As seen in Table 1, 54.1% of the participants were female, 45.9% were male, their professional experience ranged from 2 to 51 years, and 45% of them were Associate Professor and 37.5% were Professor in terms of academic title. In addition, the participants specialized in three main areas of biology: Botany 25.0%, Hydrobiology 25.0% and Zoology 20.8%.

Table 1. *Demographic Characteristics of Participants*

Demographic characteristics	Participants	Frequency (n)	Percentile (%)
Gender			
Female	P3, P5, P7, P8, P9, P10, P11, P13, P16, P19, P20, P23, P24	13	54.1
Male	P1, P2, P4, P6, P12, P14, P15, P17, P18, P21, P22	11	45.9
Professional Experience(year)			
0-5	P13, P14	2	8.3
6-10	P6, P9, P11,	3	12.5
11-15	P1,	1	4.2
16-20	P2, P3, P5, P7, P10, P19, P23,	7	29.2
21-25	P8, P12, P21	3	12.5
26-30	P15, P18, P22	3	12.5
31 +	P4, P16, P17, P20, P24	5	20.8
Academic Title			
Lecturer	P13, P14,	2	8.3
Assistant Professor.	P11, P6,	2	8.3
Associate Professor.	P1, P2, P3, P5, P7, P8, P9, P10, P12, P19, P23,	11	45.8
Prof. Dr.	P4, P15, P16, P17, P18, P20, P21, P22, P24	9	37.6
Areas of Expertise			
Botanic	P1, P10, P12, P13, P20, P21,	6	25.0
Zoology	P4, P8, P15, P16, P23,	5	20.8
Hydrobiology	P6, P7, P11, P17, P19, P22,	6	25.0
Ecology/Environmental Toxicology	P2, P3, P24	3	12.5
Molecular Biology and Genetics	P14,	1	4.2
Biochemistry	P5, P9,	2	8.3
Evolution	P18	1	4.2
Total		**24**	**100**

2.3. Data Collection Tools and Process

The study utilised a semi-structured interview form, comprising five demographic characteristics and eight open-ended questions, as a data collection instrument. The form was prepared by the researchers to ascertain the opinions of academicians on the role of biology, as the locomotive discipline of the 21st century, in undergraduate education, the fundamental problems it addresses, and the solution suggestions put forward by researchers.

The questions to be included in the interview form were formulated on the basis of a review of the extant literature, with a view to achieving the objectives of the study. The preliminary form was submitted to three experts in the fields of biology, one in science education and one in Turkish education, in order to ascertain its content validity. The form was finalised following adjustments made in accordance with expert opinions. The form is comprised of two sections. The first section includes personal information such as gender, title, years of professional experience, university of employment and areas of specialization. The second part of the questionnaire comprises eight questions pertaining to the quality, content, problems and solutions of biology education in 21st-century education. The participant information text is incorporated within the form.

After obtaining the consent of the participants that they were volunteers, the responses were collected in writing.

2.4. Analysis of Data

The personal data section of the interview form was analyzed descriptively, and the responses to the open-ended questions in the second section were analyzed through content analysis. Content analysis involves the systematic identification, organization, and interpretation of meaningful patterns in qualitative data. This allows recurring themes to be identified and the relationships between these themes to be evaluated with a holistic approach (Creswell, 2009).

Validity in qualitative research is achieved by observing the phenomenon under investigation as objectively as possible. The data obtained as a result of the research were examined impartially and reported as is, increasing validity. To ensure the reliability of the research, the authors coded the obtained data separately, created subthemes, compared them, and identified points of consensus and disagreement after all comparisons (Yıldırım & Şimşek, 2013). Consistency between the codes was calculated using the formula [Reliability = Agreement / (Agreement + Disagreement) x 100] (Miles & Huberman, 1994). Accordingly, the percentage of agreement was calculated as 91.7%. Where there were disagreements, the authors discussed and reached a common theme. The data were interpreted as themes and subthemes, and the findings were presented in tables. The themes in the table were supported by direct quotes from the participants' opinions. To protect the participants' personal rights, codes (P1, P2, … P24) were used instead of names.

3. RESULTS / FINDINGS

This section should give results obtained from the study. In this section, you must present the findings you obtained from your research in order according to the sub-objectives of your research.

3.1. The Place of Biology Education in Twenty-First Century Türkiye

Participants were asked an open-ended question as ‘What is the place of biology education in the education of 21st century youth?’. The participants' views on the place of biology education in the 21st century were grouped under 4 themes and the findings are given in Table 2.

Table 2. *Academics' Views on the Place of Biology Education in the Education of 21st Century Youth*

Thema	Codes	Participants	Frequency (n)
21st Century Biology Education	Provides the solution of current world problems.	P2, P3, P5, P8, P9, P11, P20, P22	8
	It is a basic science that forms the basis for many disciplines.	P1, P7, P9, P10, P22, P23, P24	7
	It is necessary to recognise the universe, nature and society.	P4, P7, P10, P20, P22	5
	Integrated with technology.	P19, P21	2

To the question ‘*What is the place of biology education in the education of 21st century youth*?’, all of the participants emphasised the importance of biology education in the 21st century and stated that biology is a basic science that covers every subject related to living things and nature, that it is a discipline that forms the infrastructure for disciplines in many fields from agriculture to health and engineering, that it is important for the individual to recognise himself, his environment and nature, and that it is a discipline that forms the 21st century technology. Some of the participants' responses to the themes in Table 2 are presented below:

P5: "*Today, most of the problems facing our country and the world—environment, population growth, production, health, nutrition, and infectious diseases—are of biological origin. Biology education is crucial in solving these problems. The existence, location, benefits, and importance of species in nature can only be understood through knowledge of biology. People need biology education in many areas, such as a beautiful and natural environment, healthy living, reproduction, and nutrition."* emphasizes the problem-solving aspect of biology.

P1: "*Biology education must be paramount in the education of 21st-century youth. This is because medicine, pharmacy, and some engineering departments are rooted in biology, one of the fundamental sciences. Every development in biology also impacts developments in these branches*." This statement highlights the interdisciplinary dimension of biology.

P10: "*Biology is the most important basic science. … The fact that it forms the foundation of important fields such as agriculture, forestry, and medicine, and that biologists undertake important roles and achieve success in research studies at relevant institutions, demonstrates the importance of biology education. … This course should be given due importance not only in universities but also in middle and high schools so that each individual can understand themselves and their environment and live their lives more consciously and meaningfully."* This statement highlights both the interdisciplinary dimension of biology and its contributions to the individual.

P2: "*Science, and biology in particular, will be decisive in shaping human life today and in the future, defining human-environment relationships, and humanity's survival as a part of the ecosystem in which it is a part. In this respect, biology education is important*."

P21: "Biology should be taught by integrating technology and biology in line with technological advancements. … Emphasis should be placed on biotechnology."

P24: "*Biological science is a basic science that forms the basis of applications in the fields of food, agriculture, forestry, health, and the environment. Subsequently, fields such as biotechnology, materials science, and bioengineering have evolved from this basic science."*

As can be seen from the explanations above, the vast majority of academicians stated that biology science has a multidisciplinary structure (7 participants), is necessary to recognize nature and society (5 participants) and provides solutions to today's problems (8 participants), while only 2 participants stated that it is integrated with technology.

3.2. Quality and Standarts of Biology Education in Türkiye

Participants' responses to the question, "Does applied biology education in Türkiye have sufficient quality and standards?" are presented in Table 3.

Table 3. *Academics'* Views on the Quality of Current Biology Education in Türkiye

Theme	Sub-themes	Codes	Participants	Frequency (n)
The Quality of Current Biology Education	Insufficient	Inadequate physical structure and technical equipment	P1, P4, P6, P7, P9, P10, P13, P24	8
		Insufficiency of academic staff	P1, P4, P6, P10, P15, P24	5
		Education based on rote learning	P3, P4, P5, P19, P21	5
		Frequent changes in curricula	P3,	1
		Inadequate research and support facilities	P1, P24	2
		Lack of standards and accreditation	P14, P17, P22,	3
		Political inconsistencie	P2, P10,	2
		Inadequate student quality and interest	P8, P11, P23,	3
	Partially Sufficient		P16, P20,	2
	Sufficient		P12	1

In response to the question of whether the quality of biology education in practice in our country is sufficient, 21 people "*insufficient*," two "partially sufficient," and one answered "*sufficient*." Those who answered partially adequate stated that large or major universities are adequate, but provincial and newly opened universities are inadequate.

Examples of participants' responses to the themes in Table 3 are presented below.

P1*: "Definitely not. The number of faculty members, elective courses and their contents, laboratory conditions, research facilities and financial support for research are different in each biology department."*

P4*: "It is not sufficient. Because firstly, there are not enough tools and physical facilities. Secondly, the educators working in Biology education unfortunately cannot establish a relationship between the subjects and convey their importance in our daily lives to the students. Therefore, the Biology course is reduced to a position where the information given is completely memorised and useless."*

P8: "In my opinion, current biology education does not have sufficient quality and standards. One of the reasons for this is that the students do not show sufficient interest in the department due to the problems in education and the lack of job opportunities."

P17*: "There is a lot of material, but there is a lack of application and presentation. Quality and standards are very low. There is a gap between the quality and standards of biology education between schools."*

As the examples of participants' statements above show, they explained that the quality of biology education in our country is insufficient and lacks a certain standard. The situations that the participants stated to be insufficient were insufficient of physical and technical equipment (8 participants), insufficient of staff (5 participants) and rote-based education practices (5 participants) ranked in the top three.

3.3. Content of the Curriculun for Biology Education to Meet the Requirements of the 21st Century

Participants' responses to the question "What should a Biology Curriculum include to meet the needs of the 21st century?" were grouped under three themes and the findings are presented in Table 4.

Table 4. Academics' Views on the Curriculum of a Biology Education to Meet 21st-Century Needs

Theme	Sub-themes	Codes	Participants	Frequency (n)
Biology Curriculum	Aims	For today's problems and solutions	P2, P11,	2
		Context-based	P18,	2
		Biology literate	P3,	1
	Content	Nature-based, system approach, holistic and sustainable	P4, P5, P7, P10, P14, P15, P17, P18, P19, P22, P24	11
		Compatible with scientific and technological developments	P5, P6, P7, P14, P15, P19, P22	7
		Connected to current developments	P7, P8, P18, P21, P22, P24	6
		Providing specialisation at the undergraduate level / with emphasis on departments	P1, P6, P7, P10, P13, P23	6
		Interdisciplinary	P9, P10, P11, P20, P24	5
	Learning-Teaching Approaches	Application-oriented	P3, P4, P9, P10, P11, P12, P14, P15, P16, P19, P20, P23, P24	13
		Developing scientific process skills	P4, P5, P7, P14, P15, P16, P18, P19, P22	9
		Inquiry	P4, P5, P7, P14, P15, P19,	6
		Project-based	P1, P9, P20, P23, P24	5
		Student-centered	P3, P10, P19	3
		Contex-based	P10, P18	2

Participants' views on the aims of the "content of the biology program that will meet the needs of the 21st century" were grouped under 3 titles: "For today's problems and solutions" (2 participants), "Context-based" (2 participants) and "Biology literate" (1 participant). In the content of the biology curriculum; 5 sub-themes were identified as "Nature-based, System approach, Holistic and Sustainable" (11 participants), "Compatible with scientific and technological developments" (7 participants), "Linked to current developments" (6

participants), "Providing specialization at undergraduate level / Departments weighted" (6 participants) and "Interdisciplinary" (5 participants). Learning-teaching approaches were grouped under 5 themes: "Developing scientific process skills" (9 participants), "Inquiry" (6 participants), "Project-based" (5 participants), "Student-centered" (3 participants) and "Context-based" (2 participants). The participants did not express any opinion about the measurement and evaluation process.

P3: *"First of all, it should be a program that will take students away from ready-made request, make them more active, develop their ability to learn by doing and experiencing, and make them truly biology literate."*

P10: "*In order for the science of biology to take its real place and value in our country, it should be revised, ... innovative approaches should be taken in the research fields and education of biology. Since biology is a multidisciplinary branch, interdisciplinary collaborations should be established to transfer knowledge to application areas. ... From the 3rd grade onwards, students should be allowed to specialize by taking into account their areas of interest. Since this branch of science is a life science, students should be provided with access to nature ...."*

P18: *"-Bearing basic scientific criteria, -Comprehending nature from a holistic and rational perspective, - Directly related to society and individual life, - With a content at the level of contemporary knowledge."*

P24: "*Biology education as a basic science in the twenty-first century should emphasize bioinformatics, laboratory applications and field studies. Innovative approaches should be followed with international programs, ... students should take part in scientific projects and learn science ethics, culture and scientific approaches ..."*

The most frequently emphasized views of the participants in order to educate the 21st century individual were that; the aim should be oriented towards today's problems and solutions and be Context-based; the content should be "Nature-based, System-oriented, Holistic and Sustainable" and the approach should be application-oriented.

3.4. Main Problems in the Biology Education Process

The participants' answers to the question "What are the main problems in 21st century biology education?" were grouped under 2 themes and the findings are given in Table 5.

Table 5. Academics' Views on the Main Problems in 21st Century Biology Education

Thema	Sub-themes	Codes	Participants	Frequency (n)
The Main Problems in Biology Education	Problems Related to the Teaching and Learning Process	Rote learning and decontextualized approaches	P1, P2, P9, P19, P20, P21,	6
		Inadequacy of practice and experience	P19, P23,	2
		Outdated content	P2, P14, P21, P22,	4
		Students' negative attitudes, low motivation and inadequate preparedness	P1, P2, P19,	3
		Inadequate quality and/or quantity of teaching staff	P1, P2, P3, P4, P6, P18, P19, P24	8
	Institutional, Social and Political Challenges	Inadequate technical and physical facilities	P2, P3, P4, P6, P14, P19, P24	7
		Society's lack of interest in science	P13, P18,	2
		Financial constraints	P14	1
		Recruiting more students than needed	P23,	1
		Political and bureaucratic barriers	P1, P6, P10, P11, P12, P18, P24	7
		Anxiety about the future/not finding a job	P7, P11, P16, P17, P23	5

The main problems in 21st century biology education were grouped under 2 main themes and 11 sub-themes (Table 5). Examples of participant views in Table 5 are given below.

P2: "*Today,* the *amount of knowledge in every branch of science is increasing very much. It is not possible, nor is it meaningful, to provide all knowledge through education. The lack of education based on practice and experience, and even the lack of material and intellectual knowledge of how to do this, leads the system towards information overload. ..."*

P10: *"Due to the constantly changing national education programs and examination systems, students who come to the biology department come to the department not willingly, but only with the understanding and approach of "being a university graduate". Unfortunately, students who come to provincial universities outside of metropolitan cities come with insufficient basic knowledge about science from primary school years, which causes students' communication with the courses and their indifferent and reluctant approach to the department courses."*

P17 *"Biological science is not seen as a viable career option for students. The outputs of biological science are mostly owned by the fields of agriculture, medicine, veterinary and environmental engineering."*

P18: *"Society's apparent disinterest in science, deficiencies the academic community and its outputs (students, theses, publications, patents, products), and the absence of government and state policy."*

P21*: "Emphasizing classical education rather than current needs ...*

P23*: "Even students studying in the 4th grade do not have a biological" perspective. Students do not give due importance to undergraduate education due to unemployment anxiety. Inadequate applied education. The high number of students enrolled in biology departments. .. practices of the current governments that weaken and do not support basic sciences."*

P24: *the establishmentof a large number of new universities even with insufficient quality and infrastructure; ... scholarships for doctoral candidates are not augmented and allocated in accordance with political preferences, resulting in a paucity of doctoral researchers.."*

As can be seen from Table 5 and the quotes above, some of the problems academics have expressed regarding biology education in Türkiye (physical, technical, and personnel inadequacy, inadequate student preparedness, and negative attitudes) are expressed under all circumstances.

As can be seen from Table 5 and the quotes above, some problems with biology education in Türkiye (physical, technical, and personnel inadequacy, inadequate student preparedness, and negative attitudes) are expressed under all circumstances.

3.5. Actions to Improve the Quality of Biology Education, Solve Problems, and Ensure It Becomes a Priority Choice

Participants' opinions on what needs to be done to improve the quality of biology education, solve its problems, and ensure it becomes a priority choice are presented in Table 6.

As seen in Table 6, the participants' views on what needs to be done to improve the quality of biology education, solve problems and make it one of the priorities consist of 3 themes and 13 sub-themes**.**

P8: *"... students should be taught current issues. An education system that aims to raise a student mass that asks and researches, away from rote memorization should be implemented. ..."*

P14*: "Education curriculum with more practice and constantly renewed information resources….*

P24*: "Department quotas should be reduced to the optimum level due to quality assurance and scientific approach. Joint education and exchange programs should be carried out with foreign countries in order to follow the innovations in the fields of basic sciences in the world. ... The importance of basic sciences should be included in the programs of the governments in a way to create awareness in the society. ...Research (R&D) should be given the necessary importance. For example, research-oriented institutes should be established in higher education institutions, independent of undergraduate programs. ...The first 10,000 students who enter with high scores at the undergraduate level should be given basic sciences scholarships based on their preferences. More support from EU funds…*

As can be seen from Table 6 and the example explanations, the most prominent recommendations include increasing job opportunities, addressing research, physical, technical, and teaching personnel shortages, implementing inquiry-based, application-based, and project-based teaching, increasing research and scholarship support, and prioritizing R&D.

Table 6. Academics' Views on What Needs to be Done to Improve the Quality of Biology Education, Solve Problems and Make it a Priority Choice

Thema	Sub-themes	Codes	Participants	Frequency (n)
Actions to Improve the Quality of Biology Education	Things that should be done on a professional level	Increasing job opportunities	P2, P3, P4, P6, P10, P11, P12, P13, P14, P17, P19, P21, P22, P24	13
		Establishment of a professional chamber	P1, P4, P10-15, P24	9
		The quality and quantity of teaching staff should be increased	P1, P3, P4, P6, P14, P15, P19, P21	8
	Things that should be done during the Teaching-Learning Process	Applied and project-based teaching	P1, P3, P7, P8, P9, P14,	6
		Inquiry and awareness-raising education should be provided at all levels	P5, P7, P16, P19, P21, P22, P23	7
		Lessons should be updated	P3, P7, P8, P14, P22	5
		Accreditation should be ensured	P1,	1
		Inter-institutional cooperation and joint projects should be established	P8,	1
	Things that should be done at the political level	R&D activities should be emphasized and state support should be increased	P20, P23, P24	3
		Scholarship opportunities should be provided	P8, P10, P24	3
		Increasing physical and technical facilities	P4, P6, P7, P14	4
		Number of students should be reduced	P1, P6, P17, P5, P23, P24	6
		Research centers, science centers and natural history museums etc. should be established	P17,	1

4. DISCUSSION and CONCLUSION

In this section, the findings obtained from the analysis of academics' views on the problems and solutions in biology education in 21st-century Türkiye are discussed in light of the relevant literature.

The contemporary world is confronted with a series of interrelated challenges, including, the escalating human population, food shortages resulting from population growth, the depletion of natural resources, the destruction of the natural environment, the loss of biodiversity, and other related issues. Essentially, all of these problems appear to be the problems that biology focuses on (Kim, & Diong, 2012). These are problems that can be solved with the concepts, methods, theories and technologies of biology. The solution to problems is possible through effective, inquisitive, context-based quality education that includes up-to-date information (United Nations [UN], 2015; Wibowo & Saidikin, 2019). Biological science and biology education show how to use natural resources in sustainable ways and how to overcome problems with scientific methods.

NRC (2009) calls biology in the 21st century world as “new biology” and emphasizes that in order for new biology to be a research community capable of solving scientific, social and economic problems that will meet the needs of the 21st century, it should be integrated and restructured with many sub-disciplines within itself and with computational disciplines such as chemistry, mathematics, engineering, physics and computer science (Kim & Diong, 2012; Labov, et al, 2010; Osman, et al., 2013; Wake, 2008; Zaikina, 2007). In their answers to the first research question of the study, “What is the place of biology education in the education of the youth of the 21st century?”, the academics stated that 21st century biology education should be

multidisciplinary, and integrated with technology in order to produce solutions to current problems and to enable the youth to recognize society, nature and the universe (Table 2).

Curricula are one of the basic components of the formal education process. It consists of four basic components: planning, content, implementation and evaluation processes, including objectives for a certain field, what (content) and how (learning-teaching approach-strategy-method-technique) will be taught to achieve these objectives, and measurement-evaluation approaches to determine how much of these objectives have been achieved (Demirel, 2005).

Since curricula have a dynamic and variable structure, its need to be revised or changed. According to Atik (2023), the biology curriculum in Türkiye has changed six times (1924, 1935-1957, 1976, 1985, and 1998) from the founding of the Republic until the 2000s (Atik, 2023). After the 2000s, radical changes were made not only in biology but in all programs almost every six years (Ministry of National Education [MoNE], 2007, 2013, 2018, and 2024), perhaps to adapt to the rapid changes in 21st-century information technologies. On the other hand, fundamental changes are rarely made at the undergraduate level. The achievement of the desired goals of the developed programs depends on the effective participation of all stakeholders and the improvement of all conditions. In addition, it is necessary to conduct research in the field in order to identify the shortcomings of the developed programs, the problems encountered in their implementation, to find solutions to these problems, and to make comparisons (Demir & Demir, 2012). Since the 2000s, studies on biology programs developed in Türkiye can be grouped into two categories: research aimed at identifying problems and deficiencies, and research on program outcomes. Studies have been conducted with teachers (İpek, et al., 2021; Öztaş & Özay, 2004), students (Yeşilyurt & Gül, 2008), and academics (Vekli, 2018) to determine the problems and deficiencies in the program. Although the target group is different, in all these studies, the problems related to the problems in biology teaching such as inadequate physical and technical facilities, especially laboratories, inadequate readiness of students, negative attitudes towards biology course and rote learning are the findings that have been included in most of the studies conducted from past to present and show continuity. However, these problems are not unique to Türkiye; similar issues have also been highlighted in studies conducted in other countries (Hambabi, et al., 2024; Wei, 2020). These findings were also found in the current study (Table 3).

The findings of this study suggest that biology education should have the qualities mentioned above. The academicians stated that the biology curriculum should be solution-oriented, aiming to educate biologically literate individuals, allowing specialization at the undergraduate level, learner-centered, inquisitive, project-based and interdisciplinary cooperation, current, system-oriented, holistic and sustainable nature (Table 4).

A study by Atik and Yetkiner (2021) examined the integration of 21st century skills within the middle school biology curriculum. The study found that while 21st century skills were incorporated, the implementation was not adequate. Furthermore, the distribution of these skills across different classes was found to be imbalanced. Specifically, skills related to learning and innovation were more prevalent in all classes, while life and career skills were comparatively less represented. Additionally, skills such as higher-order thinking, information, and media literacy could not be developed sufficiently (Atik & Yetkiner, 2021). In the study conducted by Çakır and Senemoğlu in 2016, it was determined that the analytical thinking skills of university students were low, but the effectiveness of the education they received at university and the richness of their learning experiences contributed to the development of their analytical thinking skills..

Atmaca and Bumen (2023), in their study on the interdisciplinary nature and interconnectedness of the 2018 Biology Curriculum (MoNE, 2018), noted that the program exhibited a partially interdisciplinary nature and was interconnected with other courses (Atmaca & Bumen, 2023). Similarly, Köse (2016), in here study comparing the interdisciplinary status of various biology curricula in Türkiye, England, Germany, and the United States, noted that, unlike the other three countries, biology programs in Türkiye lacked an interdisciplinary approach and insufficient courses focused on this approach, and that existing courses were electives (Köse, 2016).

Natural sciences in general (since they encompass physics, chemistry, biology, earth sciences, environmental sciences, and similar disciplines), and biology in particular, are inherently interdisciplinary. Furthermore, the multifaceted interaction between technology, science, and society has radically changed the way we live, work,

and interact (Alemayehu Tegegn, 2024). Therefore, interdisciplinary competence and collaboration are crucial in both academic and business settings, as well as in solving global problems (Braßler, 2020; Holman & Švejdarová, 2023; Labov et al., 2010; Organisation for Economic, Co-operation and Development [OECD], 2019). In today's world, individuals, researchers, and consumers, exposed to the overload of information ('big data') easily generated and disseminated through digital tools, need certain skills and competencies (e.g., metacognitive skills such as accessing accurate information, sorting, analyzing, evaluating, and synthesizing information, as well as critical and context-based thinking, effective communication, and information, media, technology, and scientific literacy) that will facilitate their adaptation to the 21st century (Partnership for 21st Century Skills [P21], 2009). Therefore, all curricula and educational processes, particularly those in science and biology, need to be restructured to cultivate individuals who are knowledgeable about interdisciplinary, collaborative, and effective communication methods, who can think critically, analytically, and holistically, and who have developed problem-solving skills—in short, who are equipped with 21st-century skills.

Studies on science education in Türkiye have highlighted common problems such as the qualitative and quantitative inadequacies in physical, technical, and teaching personnel, and low student readiness and motivation(Ayvacı & Bebek, 2018; Balbağ et al., 2016; İpek et al., 2021; Vekli, 2018; Kuru Kaçmazoğlu & Taşcan, 2019). In addition to these problems, academics stated that undergraduate biology programs are outdated, traditional, and disconnected from context. Furthermore, students are not sufficiently involved in the application, research, or even learning process. Instead of specializing in a specific field, they believe learning a little bit of everything is sufficient. This situation increases the anxiety about not finding a job and the future. Furthermore, they also noted political and bureaucratic obstacles (Tablo 5). The quality of the teaching staff is a crucial factor in integrating program changes into the educational process and achieving the desired outcomes. Therefore, the qualifications of teachers and academics must be enhanced through pre-service and in-service training (Hambabi, et al., 2024). Similarly, the academics participating in the study recommend a promising education system that includes improved physical conditions, highly qualified educators, research, inquiry, project-based student-centered practices, and interdisciplinary integration and collaboration, all in line with 21st-century conditions (Table 6).

In light of the study's findings, the following recommendations are offered for biology education that will foster 21st-century individuals and biologists:

● National Science Education Standards should be developed.

● Comprehensive and continuous professional development programs should be developed to improve the knowledge, skills, and attitudes of program implementers.

● Biology curriculum should be updated from preschool to graduate level.

● A professional chamber should be established, and programs tailored to contemporary content, free from political pressures, should be developed.

● Starting with graduate education, biology should be fully integrated with disciplines such as physics, chemistry, mathematics, computer science, and bioinformatics, and this should be gradually implemented down to lower levels. Furthermore, to ensure full integration and collaboration, biology should be included as a compulsory course in the programs of these fields.

● Instead of centralized, multiple-choice exams, alternative methods and techniques should be implemented to develop context-appropriate, critical, and creative problem-solving skills, enabling students to analyze, synthesize, and evaluate, as well as develop metacognitive skills through case studies and problems.

● Life sciences should be structured as a faculty-level educational unit, and bioinformatics, molecular biology, genetics, evolution, bioengineering, biomedical engineering, environmental engineering, and similar disciplines should be structured under this unit.

In conclusion, in the 21st century, do we want biologists and biology teachers to be future bioinformatics scientists or bioinformatics technicians? We must decide! We must restructure our paradigm of "doing" science and "teaching" science in a way that responds to the challenges and changes in life in the 21st century (Kim, & Diong, 2012 p.1-4), is sustainable, holistic, interdisciplinary collaborative, and provides life skills.

Acknowledgments

*This research was presented as an oral presentation at the 2nd International Painting Exhibition and Symposium on Philosophy, Education, Arts and History of Science held at Muğla Sıtkı Koçman University from May 3-7, 2017, and was subsequently developed and updated.

Declaration of Conflicting Interests and Ethics

The authors declare no conflict of interest. This research study complies with research publishing ethics. The scientific and legal responsibility for manuscripts published in IJEDAI belongs to the author(s).

Authorship Contribution Statement

Emine KURU KAÇMAZOĞLU: Conceptualization, Methodology, Analysis and Interpretation, Writing,
Nesrin ÖZMEN: Conceptualization, Methodology, Analysis, Writing, Data collection,

REFERENCES

Alemayehu Tegegn, D. (2024). The role of science and technology in reconstructing human social history: effect of technology change on society. *Cogent Social Sciences*, *10*(1), 2356916.

Atik, A. D. (2023). 1998-2018 Yılları arasında yayınlanan biyoloji öğretim programlarının karşılaştırılması. *Uluslararası Eğitimde Mükemmellik Arayışı Dergisi (UEMAD), 3(2), 34-53.*

Atik, A.D. & Yetkiner, A. (2021). Biyoloji öğretim programı kazanımlarının 21. yüzyıl becerileri açısından incelenmesi, *Trakya Eğitim Dergisi*, 11(2), 745-765. https://doi.org/10.24315/tred.707904

Atmaca, E. & Bumen, N. (2023). Biyoloji öğretim programlarının yatay ve dikey kaynaşıklık açısından incelenmesi. *Dokuz Eylül Üniversitesi Buca Eğitim Fakültesi Dergisi*, (57), 1341-1387

Ayvacı, H. Ş., & Bebek, G. (2018). Fizik öğretimi sürecinde yaşanan sorunların değerlendirilmesine yönelik bir çalışma. *Kastamonu Education Journal*, *26*(1), 125-134. https://doi.org/10.24106/kefdergi.375680

Bialek, W., & Botstein, D., (2004), Introductory science and mathematics education for 21st-century biologists, Science, 303, 788-790.

Boodhoo, R., (2024). Biology in the digital era: exploring the intersection of science and tecnology. *Global Research Journal (September 28, 2024). Doi: 10.57259/GRJT9459*

Braßler, M. (2020). Interdisciplinary teaching and learning-theory, empirical results, and practical implications. *Proceedings of ICERI2020 Conference 9th-10th November 2020.*

Brooks, H. (1994). The relationship between science and technology. *Research Policy*, 23, 477-486.

Creswell, J. W. (2009). *Research designs. Qualitative, quantitative, and mixed methods approaches* (3rd ed.). Sage Publication

Çakır, A. N., & Senemoğlu, N. (2016). Yükseköğretimde analitik düşünme becerileri. *Kastamonu Eğitim Dergisi*, *24*(3), 1487-1502.

Demir, S., & Demir, A. (2012). Türkiye'de yeni lise öğretim programları: sorunlar beklentiler ve öneriler. *İlköğretim Online*, *11*(1), 36-50.

Demirel, Ö. (2005). *Kuramdan Uygulamaya Eğitimde Program Geliştirme*. Ankara: PegemA Yayıncılık.

Hambabi, K. T., Tileni, N. L. L., & Moses, C. (2024). Exploring teachers' perspectives and challenges in implementing the revised biology education curriculum: a case study of the ompundja circuit. *Creative Education*, *15*(5), 838-855.

Holman, D. & Švejdarová, E. (2023). The 21st-century empowering wholeness adaptive (ewa) educational model transforming learning capacity and human capital through wholeness systems thinking towards a sustainable future. *Sustainability*, *15*(2), 1301.

İpek, Z., Atik, A.D. & Erkoç, F., (2021). Ortaöğretim biyoloji öğretmenlerinin biyoloji öğretiminde karşılaştıkları güçlükler. *Turkish Journal of Educational Studies*, *8*(2):241-290.

Khan S, Ullah M.W, Siddique R, Nabi G, Manan S, Yousaf M, & Hou H. (2016). Role of recombinant dna technology to improve life. *International Journal of Genomics*, 2, 1-14.

Kim, M. & Diong CH. (Eds.), (2012). *Biology education for social and sustainable development*, Sense Publisers, Rotterdam/Boston/Taipei.

Klymkowsky, M.W, Garvin-Doxas K, & Zeilik M. (2003). Bioliteracy and teaching efficacy: what biologists can learn from physicists. *Cell Biol Education, 2*(3), 155-61.

Köse, E. Ö. (2016). Disiplinlerarası öğretim yaklaşımı ve biyoloji öğretmenliği programlarının incelenmesi. *Hasan Ali Yücel Eğitim Fakültesi Dergisi*, *13*(2), 17-26.

Kuru Kaçmazoğlu, E., & Taşcan, M. (2019). The views of academicians about problems in the science teacher education departments and their proposed solutions. *Pegem Eğitim ve Öğretim Dergisi, 9*(3), 653-672, http://dx.doi.org/10.14527/pegegog.2019.021

Labov, J. B., Reid, A. H., & Yamamoto, K. R. (2010). Integrated biology and undergraduate science education: A new biology education for the twenty-first century?. *CBE-Life Sciences Education*, 9(4), 513–523. https://doi.org/10.1187/cbe.09-12-0092

Lartigue C., Glass J.I, Alperovich N., Pieper R., Parmar P.P., Hutchison C.A., 3rd, Smith HO, & Venter J.C. (2007). Genome transplantation in bacteria: changing one species to another. *Science*. 3;317(5838):632-638.

Miles, M.B. & Huberman, A.M. (1994). *Qualitative data analysis: An expanded sourcebook.* Thousand Oaks, CA: Sage.

Ministry of National Education [MoNE]. (2024). Ortaöğretim Biyoloji Dersi Öğretim Programı (9, 10, 11 ve 12. Sınıflar). https://mufredat.meb.gov.tr/

Ministry of National Education [MoNE] (2018). Ortaöğretim Biyoloji Dersi (9, 10, 11 ve 12. Sınıflar) Öğretim Programı.). T.C. Milli Eğitim Bakanlığı Talim ve Terbiye Kurulu Başkanlığı. https://mufredat.meb.gov.tr/ProgramDetay.aspx?PID=361

Ministry of National Education [MoNE]. (2013). Ortaöğretim Biyoloji Dersi (9, 10, 11 ve 12. Sınıflar) Öğretim Programı. T.C. Milli Eğitim Bakanlığı Talim ve Terbiye Kurulu Başkanlığı. http://ttkb.meb.gov.tr/www/ogretim-programlari/icerik/72

Ministry of National Education [MoNE]. (2007). Ortaöğretim Biyoloji Dersi (9, 10. Sınıflar) Öğretim Programı. T.C. Milli Eğitim Bakanlığı Talim ve Terbiye Kurulu Başkanlığı. http://ttkb.meb.gov.tr/www/ogretim-programlari/icerik/72

Misra B.B, Langefeld C., Olivier M., & Cox L.A. (2018) Integrated omics: tools, advances and future approaches. *Journal of Molecular Endocrinology*, 62(1):R21–R45. https://doi.org/10.1530/ JME-18-0055

Moore, A. (2007). Biology education in a rapidly changing scientific and socio-economic context. *Paper presented at The International Conference GENIal Future – Genetics, Determinism and Freedom. 4-5 October, Bioscience and Society, Ljubljana, Slovenia*.

National Research Council [NRC], (2009). *A new biology for the 21st century*. Washington, DC: The National Academies Press. (98 pages) https://doi.org/10.17226/12764.

National Research Council [NRC], (2003). *Division on earth, life studies, board on life sciences, & committee on undergraduate biology education to prepare research scientists for the 21st century*. BIO2010: Transforming undergraduate education for future research biologists. https://doi.org/10.17226/10497.

Organisation for Economic, Co-operation and Development [OECD], (2019). *Future of education and skills*; OECD: Paris, France.

Osman, K., Hiong, L.C., & Vebrianto, R., (2013). 21st Century biology: an interdisciplinary approach of biology, technology, engineering and mathematics education. *Procedia Social and Behavioral Sciences*, 102:188-194.

Öztaş H. & Özay E., (2004). Biyoloji öğretmenlerinin biyoloji öğretiminde karşılaştıkları sorunlar (Erzurum örneği). *Gazi Üniversitesi Kastamonu Eğitim Dergisi*, 12(1): 69-76.

Öztürk, M. (2002). Yirmibirinci yüzyılda moleküler biyoloji. *Avrasya Dosyası, Moleküler Biyoloji ve Gen Teknolojileri Özel, 8(3):3-6.*

Partnership for 21st Century Skills. (2009). *P21 framework definitions*. ERIC Clearinghouse.

Patton, M. Q. (2014). *Qualitative research & evaluation methods* (4th ed.). Sage Publication

Quinn, H., Schweingruber, H., & Keller, T. (Eds.) (2012). *A framework for k-12 science education: practices, crosscutting concepts, and core ideas*, The National Academies Press, Washington D. C. ISBN null | DOI 10.17226/13165

Robeva, R. S., Jungck, J. R., & Gross, L. J. (2020). Changing the nature of quantitative biology education: Data science as a driver. *Bulletin of Mathematical Biology*, *82*(10), 127. https://doi.org/10.1007/s11538-020-00785-0

Scheufele D.A., & Krause N.M. (2019). Science audiences, misinformation, and fake news. *Proc Natl Acad Sci U S A*. 116(16), 7662-7669. doi: 10.1073/pnas.1805871115.

Shahrzadi, L., Mansouri, A., & Shabani, A., (2024). Causes, consequences, and strategies to deal with information overload: A scoping review. *International Journal of Information Management Data Insights*, 4(2), 100261

Steitz, JA., (2003). Commentary: Bio2010-new chalenges for biology educators, *Cell Biology Education*, 2: 87-91.

Tamborini, M. (2024). Exploring the transition: biology, technology, and epistemic activities. *Synthese* **204**, 27

United Nations. (2015, Eylül 25). *Transforming our world: The 2030 agenda for sustainable development (A/70/L.1)*. United Nations.

Vekli, G.S., (2018). Türkiye'de Biyoloji Öğretmenliğinde Yaşanan Sorunlar ve Çözüm Önerileri: Akademisyen Perspektifi. *Akdeniz Eğitim Araştırmaları Dergisi*, 12(26), 311-329.

Wake, MH., (2008). Integrative Biology: Science for The 21st Century. *Bioscience*, *58(4):* 349-353. https://doi.org/10.1641/B580410

Wei, B. (2020). An exploratory study of teacher development in the implementation of integrated science curriculum. *Research in Science Education 50*(6), 2189–2206. https://doi.org/10.1007/s11165-018-9768-x

Wibowo, Y. G., & Saidikin, A. (2019). Biology in the 21st-century: Transformation in biology science and education in supporting the sustainable development goals. *JPBI (Jurnal Pendidikan Biologi Indonesia), 5(2), 285-296.*

Yamin M. (2019). Information technologies of 21st century and their impact on the society. *International Journal of Information Technology*, 11(4), 759-766. doi: 10.1007/s41870-019-00355-1.

Yeşilyurt, S. & Gül, Ş. (2008). Ortaöğretimde Daha Etkili Bir Biyoloji Öğretimi İçin Öğretmen ve Öğrenci Beklentileri. *Kastamonu Eğitim Dergisi: 16(1)*, 145-162.

Yıldırım, A. & Şimşek, H. (2013). *Sosyal bilimlerde nitel araştırma yöntemleri* (9. Baskı). Ankara: Seçkin Yayıncılık.

Zaikina, G. A. (2007). Biological education in the age of biology. *Herald of The Russian Academy of Sciences, 77(2)*, 195-197.